SRDS Report No. RD-65-130

AD 645955

FINAL REPORT

SEVEN PARTS

Contract No. FA-WA-4409

Project No. 430-001-01R

ANALYSIS OF COMMUNITY AND AIRPORT RELATIONSHIPS / NOISE ABATEMENT

DECEMBER 1965

Prepared for

FEDERAL AVIATION AGENCY

Systems Research & Development Service

by

BOLT BERANEK AND NEWMAN, INC.

15808 Wyandotte Street

Van Nuys, California 91406

SRDS Report No. RD-65-130

FINAL REPORT

SEVEN PARTS

Contract No. FA-WA-4409

Project No. 430-001-01R

ANALYSIS OF COMMUNITY AND AIRPORT RELATIONSHIPS / NOISE ABATEMENT

DECEMBER 1965

Prepared for

FEDERAL AVIATION AGENCY

Systems Research & Development Service

by

BOLT BERANEK AND NEWMAN, INC.

15808 Wyandotte Street
Van Nuys, California 91406

FINAL REPORT

Contract No. FA-WA-4409

SRDS REPORT NO. RD-65-130

ANALYSIS OF COMMUNITY AND AIRPORT RELATIONSHIPS/NOISE ABATEMENT

TECHNICAL REPORT: WORK ACCOMPLISHMENTS, MAY 1964 THROUGH APRIL 1965

December 1965

This report has been approved for general availability

BOLT BERANEK AND NEWMAN INC.
15808 Wyandotte Street
Van Nuys, California 91406

ABSTRACT

The seven parts of this report describe engineering and research activities undertaken during the second year of a two year contract directed towards gaining a better understanding of why and how individuals and communities react to noise, and toward determining the feasibility of developing improved methods for predicting community response to noise. Part I discusses the feasibility of improving methods for predicting community response to aircraft noise and also outlines noise rating procedures for aircraft and airports. These procedures are outlined as aids in stimulating development of aircraft and airports to minimize community noise problems. The improvement of procedures for accurately predicting different degrees of community response in particular airport-community situations does not seem feasible at this time. However, present empirical methods for predicting community response to aircraft noise provide extremely useful guides to typical response expected from a broad sampling of communities.

Part II describes results of acceptability judgment tests of aircraft noise conducted in the vicinity of Los Angeles International Airport. These tests were undertaken to determine if there were significant differences in the judgment of the relative noisiness of actual aircraft flyover noise compared with recorded aircraft noise signals, and to investigate the feasibility of developing a category scale of acceptability for aircraft noise. Part III describes results of the applications of a decision-flow methodology to analysis of seventeen case histories of community-decision making. This study was undertaken to yield a basic understanding of community-airport relationships and of the methods for arriving at community decisions.

Part IV summarizes the results of noise reduction measurements made in a number of school, motel, and residential rooms. Parts V and VI present results of computer-aided studies of the noise environment generated by jet aircraft takeoffs. Part V discusses factors

determining the time duration of takeoff noise signals, particularly changes in time duration produced by changes in aircraft speed. Part VI discusses variations in aircraft flyover noise levels resulting from changes in aircraft flight paths and in atmospheric sound transmission characteristics. Part VII describes some applications of methods for determining land use compatability with aircraft noise, using the procedures outlined in Part II of FAA SRDS Report RD-64-148.

TABLE OF CONTENTS

* See individual Table of Contents for each Part.

ANALYSIS OF COMMUNITY AND AIRPORT
RELATIONSHIPS/NOISE ABATEMENT

TECHNICAL REPORT: WORK ACCOMPLISHMENTS,
MAY 1964 THROUGH APRIL 1965

PREFACE

Problems of measurement of aircraft noise, and of predicting individual and community response to noise, have been of concern to many in this country and abroad during recent years. During this time numerous studies of various aspects of this noise problem have been undertaken. Previous studies have investigated, in varying degrees of depth, such aspects as: methods for reducing engine noise at its source; laboratory psychoacoustic studies of the subjective ratings of aircraft noise; public opinion surveys to gain insight into the ways people feel about aircraft noise; engineering techniques for describing the noise environment produced by aircraft operations; and methods for estimating community response to different degrees of noise exposure.

This project has been directed towards gaining a better understanding of why and how individuals and communities react to noise, and toward determining the feasibility of developing improved methods for predicting community response to noise. To meet these objectives, a number of different studies were undertaken, involving several different disciplines. The studies undertaken can be grouped in terms of five general tasks, as stated in the contract work statement:*

1) determination of aircraft noise stimulus

---

* An additional task was originally listed in the contract work statement (Task No. 5). This task, involving consulting effort not related to the major project objectives, was later cancelled.

2) determination of subjective ratings

3) analysis of overt actions and community action potential

4) consideration of land use and zoning -- present and potential

5) overall analysis and conclusions.

This report contains seven parts, each of which is in essence a separate technical report containing information applicable to one or more aspects of the aircraft noise problem. Additional project studies were reported earlier in FAA SRDS Report No. RD-64-148.

Part I of this report deals with Task 5 above, with emphasis on the development of methods for predicting community and individual response to aircraft noise and suggestions for classifying aircraft and airports from the standpoint of aircraft noise.

Part II of this report (describing work accomplished under Task 2 above) describes results of the judgment tests of aircraft noise conducted in the vicinity of the Los Angeles International Airport. These tests were undertaken to determine if there were significant differences in judgments of the relative noisiness of actual aircraft flyover noise compared with recorded aircraft noise signals, and to investigate the feasibility of developing a category scale of acceptability for aircraft noise.

Part III (undertaken as part of Task 3) describes results of the application of a decision-flow methodology to analysis of 17 case histories of community-decision making. This study, applying modern techniques for investigating public administration problems, was undertaken to yield a better basic understanding of pertinent linkages between communities and airports and of methods for arriving at community decisions.

Part IV of this report summarizes the results of some physical measurements of aircraft noise made inside and outside of a number of school, motel, and residential

rooms. This study was undertaken to gather technical data for developing procedures for determining the compatibility of aircraft noise with different land uses in the vicinity of airports. (These procedures were described in detail in Part II of SRDS Report No. RD-64-148.)

Parts V and VI of this report present results of computer-aided studies of the noise environment generated by jet aircraft takeoffs. Part V is concerned with factors determining the time duration of takeoff noise signals, particularly, changes in time duration produced by changes in aircraft speed. Part VI is concerned with variations in aircraft flyover noise levels resulting from changes in aircraft flight paths and in atmospheric sound transmission characteristics.

Part VII of this report describes briefly some applications of the method for determining land use compatibility with aircraft noise.

FINAL REPORT

Contract No. FA-WA-4409

SRDS Report No. RD-65-130

PART I

PREDICTING COMMUNITY RESPONSE TO AIRCRAFT NOISE

December 1965

Prepared By

Dwight E. Bishop

This report has been prepared by Bolt Beranek and Newman Inc. for the Systems Research and Development Service, Federal Aviation Agency, under Contract No. FA-WA-4409. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA. This report does not constitute a standard, specification or regulation."

BOLT BERANEK AND NEWMAN INC.
15808 Wyandotte Street
Van Nuys, California 91406

ABSTRACT

Review of the many factors influencing community response to noise from aircraft operations indicates that it is not feasible at this time to develop procedures for accurately predicting different degrees of community response in particular airport-community situations. Unknowns in defining and evaluating the influence of sociological and economic factors, imperfect understanding of the decision-making processes in communities, lack of development of explicit scales for rating community response, and uncertainties in response introduced by variability in noise stimuli and individual reactions to the noise stimuli, limit development of accurate procedures. However, present empirical methods for predicting community response to aircraft noise in residential areas provide very useful guides in predicting typical response expected from sampling of a large number of communities.

Results from recent noise judgment tests generally confirm the Composite Noise Rating (CNR) boundaries defining the different zones of expected community response in the existing procedures. The test results also indicate that variability introduced by lack of correspondence between the perceived noise level scale and subjective judgments of noise acceptability is not limiting the accuracy of prediction procedures.

Noise classification procedures to be applied to both aircraft and to airports are suggested as aids in guiding development of aircraft and airports to minimize community noise problems. Standarized perceived noise level contours form the basis of the suggested classification procedures.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

APPENDIX A

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

In this project, we have been concerned with people's response to aircraft noise from a number of aspects ranging from descriptions of the aircraft noise stimulus and methods for simulating the noise stimulus for analysis and prediction purposes to descriptions of community and individual response to noise, and investigations of factors other than aircraft noise that may influence response of individuals or communities.

In Part I of this report we bring together results of our investigations and of recent work by others to examine the feasibility of improving methods for predicting "community response" to aircraft noise. We also outline complementary noise rating procedures for aircraft and to airports. These procedures are suggested as aids in stimulating long range development of aircraft and airports which will minimize community noise problems.

As other investigators before us have pointed out, the problems triggered by intrusion of aircraft noise into a community are complex. Much of our discussion in this report involves considerable simplification in description and analysis. This simplification should not obscure the complexity of many of the factors involved in describing aircraft noise and human reactions to noise. Some of these complexities have been explored in detail in the studies reported in other parts of this report or in Reference 1.

Some of the factors uncovered in these other studies are basic to understanding the discussion and conclusions presented in the body of this report. Therefore, we summarize in Section II what has been accomplished in the other project studies. This summary should be helpful in understanding the discussion presented in Section III and following sections of the report.

II. SUMMARY OF MAJOR PROJECT STUDIES

Major project studies undertaken to accomplish the first four tasks stated in the Preface to this report are summarized in this section. This summary provides a basis for the discussions to follow in the succeding sections of this report. For a more complete description of any individual study, the applicable Part of this report or of Reference 1 should be consulted.

A. Determination of Aircraft Noise Stimulus

Development of computer-aided techniques for calculating and displaying measures of the noise environment in land areas near airports received major attention in this project. This development was undertaken to make it possible to depict measures of noise exposure for varied operational and geographical situations, and to calculate variations in noise exposure resulting from differences in aircraft types, operational procedures, or flight environment.

Although most of the calculations involved in describing the noise environment at a ground position under and near aircraft flight paths are not complex in themselves, numerous and tedious calculations are generally required when describing the noise environment existing over any substantial land area. These calculations must then be repeated for any significant changes in flight paths, flight procedures, or aircraft noise characteristics. Computer techniques therefore provide a means for looking at a variety of situations which could not conveniently be studied by hand calculation alone.

The major computer programs developed under this project are:

a) Calculation of common summary measures of noise (PNdB, overall sound level, dBA or SIL) from octave band noise spectra (common or preferred frequencies).

b) Calculation of areas from graphical data (maps, noise contours); display of graphical data to arbitrary scale.

c) Calculation and display of noise contours (PNdB, SIL, etc.) for a simulated aircraft flight.

d) Calculation of the time patterns of noise exposure for arbitrary ground positions near an aircraft flight path.

e) Calculation and assembly of the maximum noise levels occurring at grid points (representing ground positions near flight paths) during a number of simulated aircraft flights; calculation of common statistical measures (mean, standard deviation, maximum) of the noise levels collected at the grid points.

Table I lists the input and output information requirements for each of the programs.

The computer programs have been applied in numerous project studies under this contract. In particular, computer techniques have been used extensively in the two studies reported in Parts V and VI of this report. In Part V, the results of an investigation of the basic parameters determining the time duration of aircraft noise signals is described. Computer-simulated flyovers of aircraft were utilized to determine the variation in time duration of aircraft noise signals resulting from typical variations in jet transport aircraft speeds during takeoff. Part VI reports the results of an investigation, by means of computer-simulated aircraft flights, of variations in noise levels received on the ground due to variations in aircraft flight paths and variations in the sound transmission characteristics of the atmosphere.

As will be stressed vigorously later in the report, the variability in noise environment encountered in actual airport situations, coupled with the variability in individual responses to noise, act to limit the accuracy with which one may predict individual or community response. Thus the investigations reported in Parts V and VI provide background understanding of some of the causes of noise level variability observed in actual field situations.

TABLE I

LIST OF INPUT AND OUTPUT INFORMATION
FOR AIRCRAFT NOISE COMPUTER PROGRAMS

Computer Program	Input Information	Output Information
Calculation of Common Summary Measures of Noise from Octave Band Spectra	Octave Band Spectra (Common or Preferred Frequencies)	PNdB, OA SPL, dBA and Given Octave Band Spectra in Tabular Form.
Calculation of Areas From Graphical Data (Maps, Noise Contours, Etc.)	Trace of the Boundary of the Area using a Graphical Input Device	1. Calculation of the Area in Tabular Form 2. Display of Area Boundaries Using the Cathode Ray Tube Display Scope or X-Y Plotter
Calculation and Display of Noise Contours for Simulated Aircraft Flight	1. Octave Band Spectra at 10^{o} intervals about particular Aircraft 2. Altitude Profile of Aircraft 3. Flight Track 4. Air Attenuation (values in Octave Bands) in dB/1000 ft. 5. Desired Contour PNdB values	Display of Specified Contours and Flight Track to Desired Scale using the Cathode Ray Tube Display Scope or X-Y Plotter
Calculation of Time Patterns of Noise Exposure	1. Octave Band Spectra at 10^{o} intervals about particular Aircraft 2. Altitude Profile of Aircraft 3. Flight Track 4. Air Attenuation (values in Octave Bands) in dB/1000 ft. 5. Temperature 6. Speed Profile of Aircraft 7. Location of Exposure Points	Plot of PNdB vs. Time for each Specified Exposure Point using the Cathode Ray Tube Display Scope or X-Y Plotter
Calculation and Assembly of the Maximum Noise Levels occurring at Grid Points during Simulated Aircraft Flyby.	1. Octave Band Spectra at 10^{o} intervals about particular Aircraft 2. Altitude Profile of Aircraft 3. Flight Track 4. Air Attenuation (values in Octave Bands) 5. Location of Grid Points	Array of Maximum PNdB values occurring at the Specified Grid Points in Tabular Form. Maximum, Minimum, Mean and Sum of the Squares of the PNdB Values at the Specified Grid Points

Early in the project many aircraft flyover noise measurements were obtained underneath the landing and takeoff path at the Los Angeles International Airport. Analysis of the variability in flyover noise levels, obtained from these measurements, has been helpful is establishing the extent of noise environment variability likely to be encountered in field situations.

B. Determination of Subjective Ratings

Considerable work has been done in this country in developing scales for judging the relative acceptability or noisiness of aircraft noise. This work has led to the development of the perceived noise level as a measure of aircraft noise.[2,3,4] However, most judgment tests have been conducted in the laboratory with subjects judging noise of recorded signals. Thus, it was felt important to confirm, by actual tests, the applicability of laboratory test findings to judgments of actual flyover noise.

With well-advanced development of an objective rating scale (perceived noise level) that corresponds well with subjective indications of relative noisiness, it appeared likely that this noise rating scale could be used to determine the absolute levels of aircraft noise which would be judged acceptable or not acceptable by people. Recent tests in Great Britain had suggested that such acceptability scales could be established for vehicle noise and for aircraft noise.[5,6,7]

To meet these needs, the field judgment tests of aircraft noise acceptability, reported in detail in Part II of this report, were undertaken to determine:

a) if there were significant differences in the judgment of relative noisiness between noise produced by actual aircraft flyovers and by recordings of aircraft noise

b) the feasibility of developing a category scale of acceptability for aircraft flyover noise.

In the tests, subjects were exposed to noise from actual aircraft flyovers and from recorded aircraft noise signals. Subjects listened to approach noise and take-off noise. In separate tests, subjects judged the noise with regard to relative acceptability and with respect to a category scale of acceptability ("of no concern," "acceptable," "barely acceptable," and "unacceptable"). Judgments were made indoors and outdoors.

Some of the test results are quite significant to the discussions to follow; they may be summarized as follows:

a) no significant difference was found in the judgments of actual or recorded signals, when judged on either a relative or on a category basis of acceptability. This finding thus confirms the value and significance of many previous laboratory experiments.

b) the feasibility of establishing a category scale for judging aircraft noise acceptability was established.

c) considerable spread, (or variability) in noise judgments on a category scale was observed. This variability, similar in magnitude to that observed in the British tests, tends to limit the accuracy with which we may predict group response.

d) analysis of the category judgment data indicates that lack of agreement between objective rating scales and subjective judgments is probably not the main source of variability. Variability in responses among subjects and lack of subject repeatibility are the probable major sources of variability.

C. Analysis of Overt Actions and Community Action Potential

Understanding of the complex linkages between the response of individuals to aircraft noise (as uncovered by psycho-acoustic tests or public opinion surveys), and various manifestations of community response and community actions is incomplete and fragmentary. In the belief that the application of modern techniques for investigating socio-logical and public administration problems might yield increased understanding of this phase of the noise problem, Professor Fremont J. Lyden, Assistant Professor of the Graduate School of Public Affairs, University of Washington, was asked to explore problems of community-decision making with particular reference to airport and aircraft noise problems.

It was originally planned to investigate decision making by field interviews of airport and local government officials directly involved in airport-community problems. Four communities located in widely separated geographical areas were selected for initial study. The study could not be undertaken, however, without approval of another Government Agency, and this could not be obtained. Rejection of this approach by the sponsor led to an alternate, less direct, approach -- the analytical investigation of 17 case histories of community decision making selected from the available literature in this field.* In this investigation, reported in Part III of this report, a "decision-flow" approach to the study of decision making was adopted.

In this approach, the reaching of a public decision (i.e., construction of a new airport, location of an expressway, etc.) was analyzed in terms of the specific events or subdecisions which were classified and placed in time relationship to one another. Each case was divided into a number of subdecisions, with each subdecision analyzed in terms of a stimulus (reasons for the event), response (identifiable action), and consequences, which usually provided the stimulus for the succeeding subdecision. Initiators of actions and other participants in each subdecision were identified and classified, as were the major inputs of information used to arrive at decisions.

---

* See Table I of Part III for the list of case histories.

The results of the study aid in our understanding of how community decisions are reached, and what groups and actors are likely to be involved in the various subdecisions. The results also suggest that airport-community noise problems are likely to be handled and resolved in the same administrative context that other community problems are handled even though new technical considerations and different interest groups may be involved.

D. Consideration of Land Use and Zoning -- Present and Potential

As reported in Part II of FAA Report RD-64-148, two simplified engineering procedures for analyzing aircraft noise in the vicinity of airports were developed. These procedures were developed as engineering tools for those concerned with airport planning and land use in the vicinity of airports. The procedures permit determination of:

a) whether or not aircraft noise will interfere with various work activities and land uses, and

b) what basic building arrangements and construction features should be incorporated in the building design, so that aircraft noise will not interfere with planned activities within the buildings.

The first procedure developed is general in nature, and defines acceptability criteria for noise generated by aircraft operations for broad categories of land use. This procedure extends methods for evaluating aircraft noise compatibility to land uses other than residential, which have been considered in earlier studies. The second procedure provides methods for developing aircraft noise criteria for specific work activities having varying degrees of dependence upon speech communication or freedom from noise interference. It also describes methods for evaluating the basic noise protection afforded by different types of building construction or building arrangements. Thus it provides a means of ascertaining, early in the preliminary design stage, the economic penalties and construction complexities likely to be involved in housing work activities in land areas exposed to varying levels of aircraft noise.

In developing the land use compatibility procedures, it was necessary to specify the average noise reduction afforded by common types of commercial and residential building construction. To supplement existing information, building noise reduction was measured in a number of school, motel and residential rooms. The results of these measurements are described in Part IV of this report. The results show that in addition to variability in noise reduction from building to building, there is considerable variability in noise reduction in the same building (or room) from flyover to flyover.

Following development of the procedures, a short study was undertaken to demonstrate the application of the procedures in evaluating land use around existing airports. The results of this study are summarized in Part VII of this report. In these applications, we applied the procedures for rating land use compatibility in study of nine takeoff or landing paths at four airports.

III. COMMUNITY RESPONSE CONCEPTS AND PREDICTION PROCEDURES

A. Two Views of the Factors Determining Community Response to Aircraft Noise

A major concern in this project has been the determination of the technical basis for methods of assessing or predicting the community acceptability of aircraft noise. In looking at this problem of assessing "community response" to aircraft noise, let us begin by briefly reviewing some of the many factors believed to affect community response to noise. Let us look, in particular, at two views of the problem put together, at different times, by two investigators.

Figure 1 shows a schematic outline of factors affecting community response to noise, as prepared by Borsky in 1961.8/ This outline had been prepared as an aid in developing and evaluating questionnaires for personal interviews. In the outline, Borsky identifies eight conceptual phases of the problem:

a) objective characteristics of the noise

b) spatial and sociological relationships of individual residents in a single neighborhood and of adjacent neighborhoods

c) intervening socio-psychological factors affecting individual feelings of annoyance

d) the range of actual individual feelings of annoyance

e) intervening socio-psychological factors affecting individual expressions of annoyance and forms of action

f) range of actual expression and forms of action

g) intervening factors affecting community action

h) forms of community action.

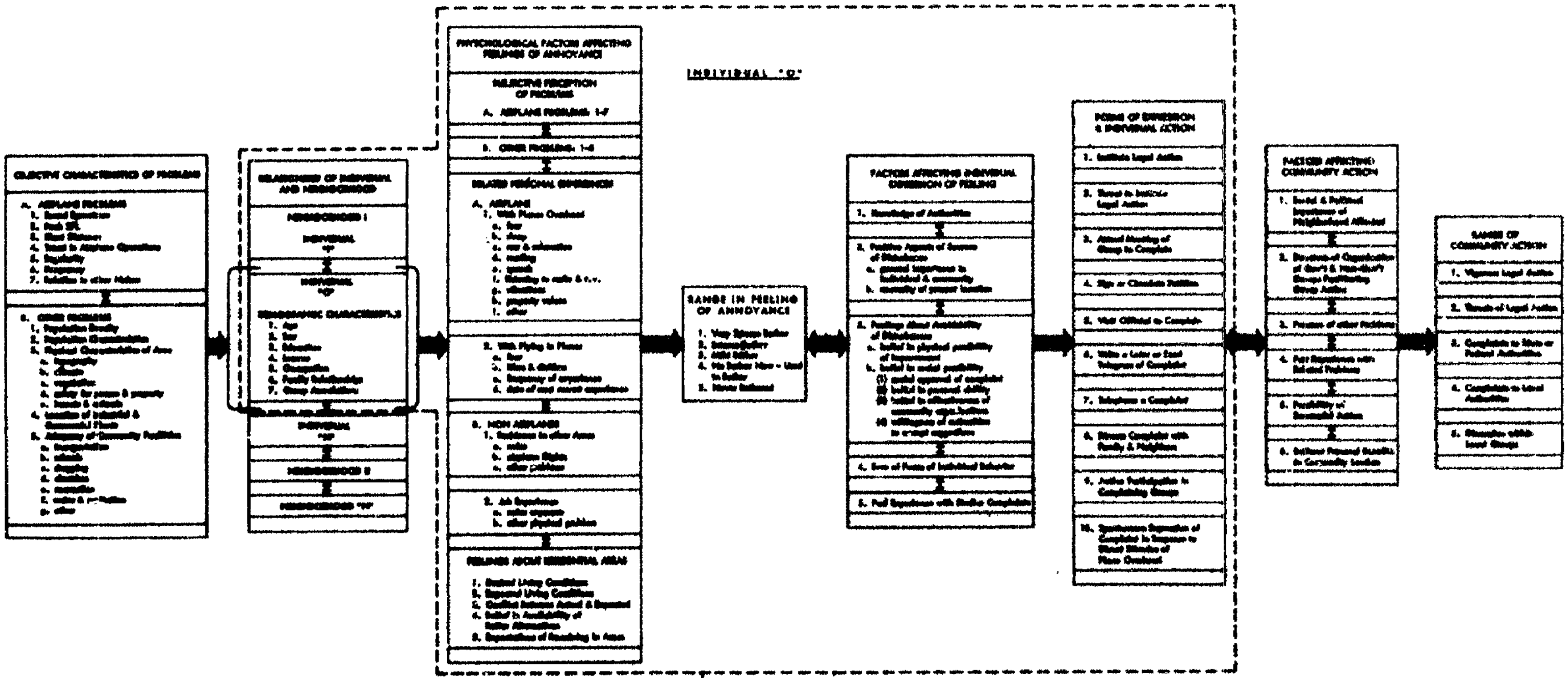


FIGURE 1. CONCEPTUAL FRAMEWORK OF COMMUNITY ASPECTS OF AIRCRAFT OPERATIONS (BORSKY)

Study of Fig. 1 emphasizes that, in addition to being able to define the noise environment in objective terms which may be meaningfully related to individual reactions to noise, there are additional factors which may determine the extent of a person's expressed feelings and his particular actions. And, since noise seldom occurs as an isolated experience but is usually part of a larger complex of problems involving residential living, expressed attitudes about noise may be influenced by these other problems. Borsky also points out that the process of relating possible neighborhood annoyance with noise to community action varies from community to community. Further, the expression of community attitudes is influenced by the structure of the community. We might note that in the last phase, listing forms of community action, Borsky has indicated a relatively simple scale of community actions ranging from "discussion within local groups" to "vigorous legal action."

Before discussing possible expressions of community action further, let us examine another view of the noise problem as outlined by Clark.1/ In Fig. 2 is an outline showing some of the stimuli, effects and overt responses resulting from airport operations. In this figure, Clark stresses the fact that airport operations produce many effects in the community, only a few of which are attributable to aircraft noise. Community responses may be a resultant of a number of these effects, making it impossible to relate responses to aircraft noise in any type of simple one-to-one correspondence.

Clark lists in the lower row of Fig. 2 various types of responses on a simple ordered scale. However, the list does not indicate fully the varied type and degree of responses that might be observed in different communities.

It appears probable that a multidimensional scale is needed to accurately portray community response to noise. An attempt to outline such a multidimensional scale is indicated in Fig. 3. In this figure, four scales of increasing intensity of response are shown. The four scales are listed in order, from bottom to top, of increasing degree of social organization. The lowest scale is of individual reactions, the next, special

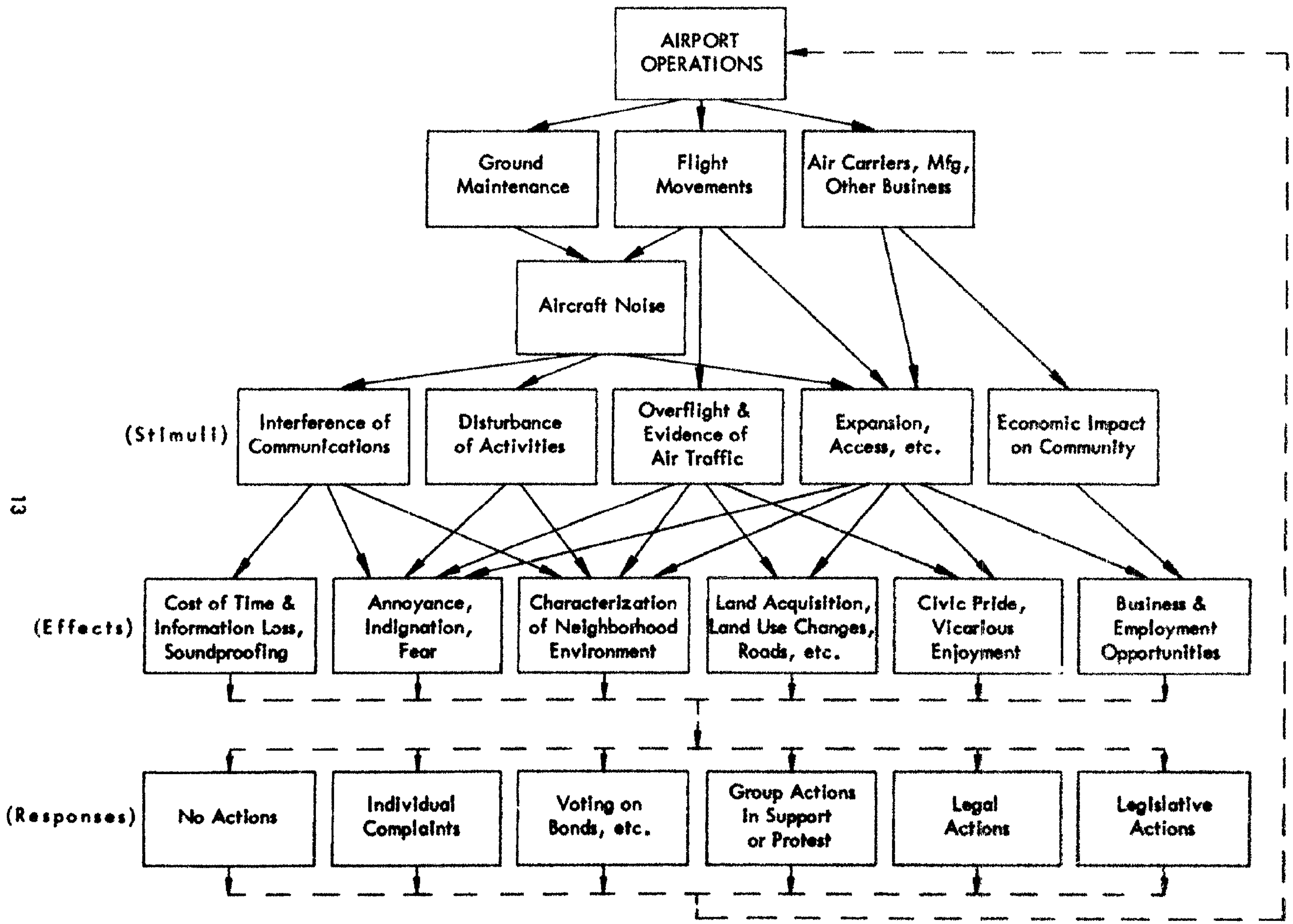


FIGURE 2. STIMULI, EFFECTS, AND OVERT RESPONSES TO AIRPORT OPERATIONS FOR ADJACENT COMMUNITIES (CLARK)

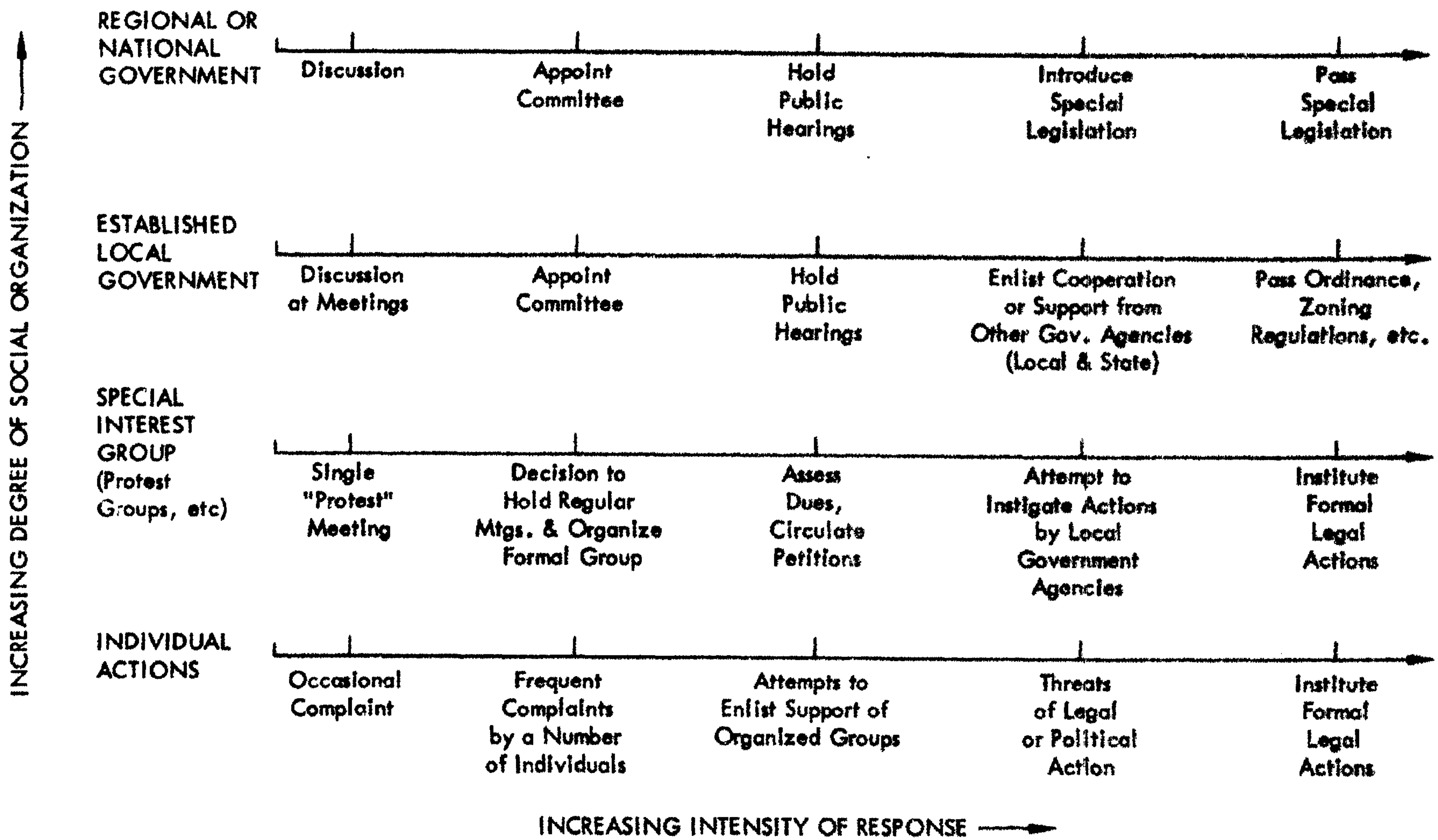


FIGURE 3. DIAGRAM INDICATING VARIOUS LEVELS AND STAGES OF COMMUNITY RESPONSE TO AIRCRAFT NOISE

interest groups, then, established local government, and finally regional or national government responses. The responses shown on each scale are indicative and are not intended to be exhaustive. Nor do individual points on one scale necessarily coincide with points on other scales directly above or below.

With respect to the response scales, several factors may be noted. Different degrees of response may occur on various levels of social organization. Thus, instead of a single scale, we might more properly use a profile to describe the community response at a given time.

The response profile changes with time. Thus, one may have to take into account changes of the profile within different time periods in accounting for the degree of community response.

The very complexities of the aircraft noise problem indicated by the above brief discussion perhaps suggests a pragmatic approach, in which detailed considerations of specific communities or individuals must of necessity be omitted. Such an approach is represented by the prediction model discussed in the next subsection.

B. Review of Current Procedures for Estimating Community Response to Noise

In Reference 9, procedures that have been quite widely used in this country for estimating community response to aircraft noise are outlined. These procedures stem directly from procedures for forecasting community reaction to noise presented by Stevens, Rosenblith, and Bolt in 1953.10,11/ This early prediction model was concerned with prediction of community reactions for different noises, not particularly aircraft noise.

In following years this prediction model was applied specifically to military aircraft noise, as reported by Stevens and Pietrasanta in Reference 12. Later, in the current procedures, the prediction model was revised to reflect description of aircraft noise in terms of the perceived noise level and to extend noise charts to include civil as well as military aircraft.

In this prediction procedure, one derives a Composite Noise Rating (CNR) as a description of the effective noise stimulus for the land area or community under consideration. The CNR is dependent upon several observations or measurements of physical noise environment:

a) the magnitude of the noise measured in terms of the perceived noise level, expressed in PNdB*

b) the number of occurrences per day

c) daytime versus nighttime operations, and

d) time duration (only for ground operations, not for flyover operations).

The calculated CNR values are then interpreted in terms of three broad categories of expected community response shown in Table II. Perhaps we may categorize the degrees of community response in Table II as Zone 1, no serious response; Zone 3, serious response; and, Zone 2, the middle zone, a "grey" area where varying degrees of response may be observed. This middle area, Zone 2, encompasses a 15 unit CNR spread.

Selection of the CNR values for zone boundaries has been based essentially upon analysis of case histories of noise problems observed at both military and civil airports. As an example of the empirical correlation, Fig. 4 shows CNR ratings and comparison with observed response for 21 case histories. It will be noted from the figure that the correlation, while satisfactory in a number of cases, is not perfect. And, further, we note that in Zone 2 (defined by CNR values of 115 and 100 for takeoff and landing noise) a variety of responses ranging from "no observable reaction" to "concerted group action" have been observed.

---

* The perceived noise level is a quantity calculated from measured noise levels that correlates well with subjective responses to various kinds of aircraft noise. It is an objective rating scale that has been developed on the basis of subjective judgments of the relative noisiness or acceptability of different aircraft sounds.2,3,4/

TABLE II

CHART FOR ESTIMATING RESPONSE OF RESIDENTIAL
COMMUNITIES FROM COMPOSITE NOISE RATING

Composite Noise Rating		Zone	Description of Expected Response
Takeoffs and Landings	Runups		
Less than 100	Less than 80	1	Essentially no complaints would be expected. The noise may, however, interfere occasionally with certain activities of the residents.
100 to 115	80 to 95	2	Individuals may complain, perhaps vigorously. Concerted group action is possible.
Greater than 115	Greater than 95	3	Individual reactions would likely include repeated, vigorous complaints. Concerted group action might be expected.

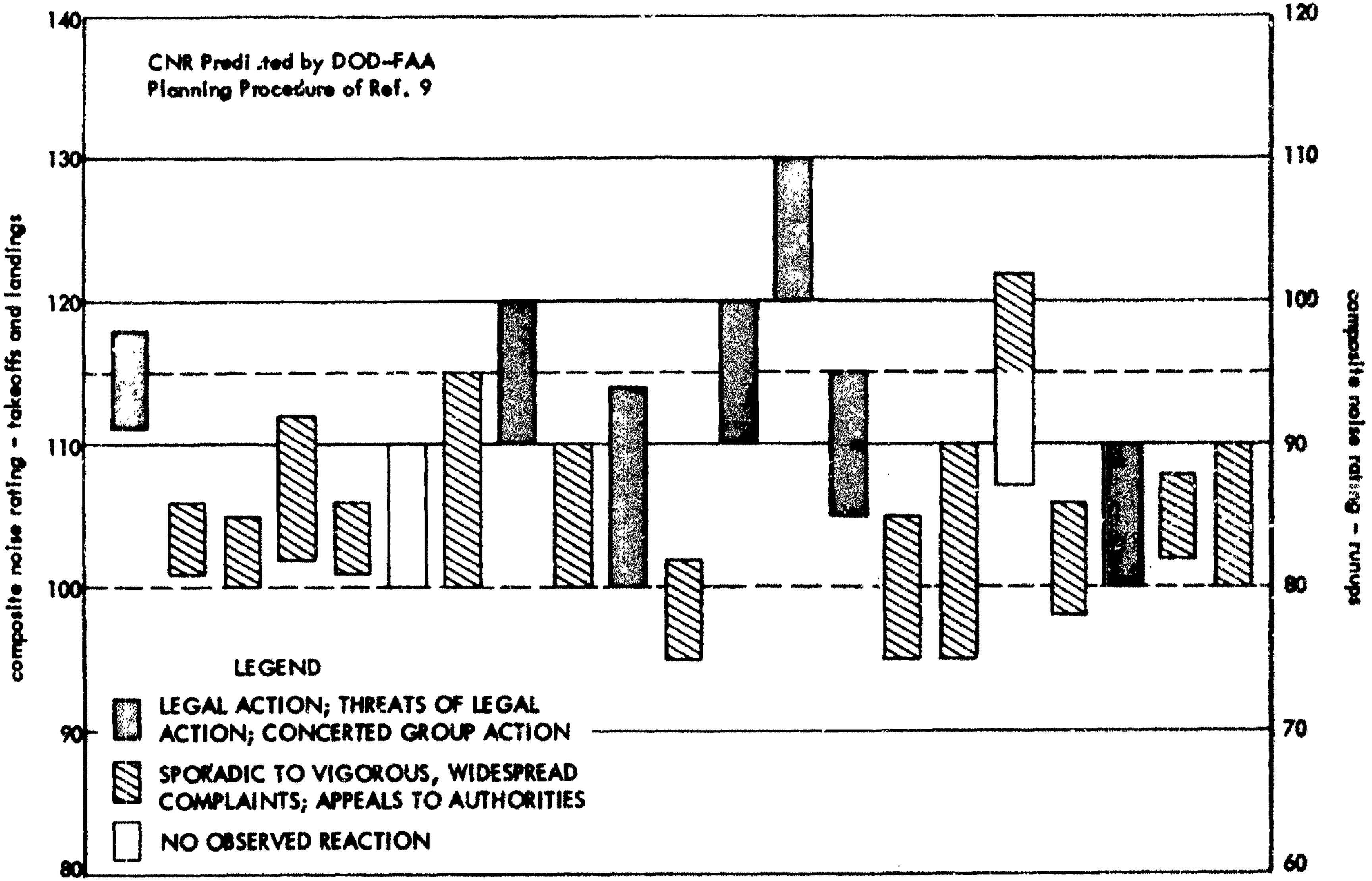


FIGURE 4. CORRELATION OF CASE HISTORIES OF OVERT COMMUNITY RESPONSE WITH COMPOSITE NOISE RATINGS

One way of visualizing progress in refining community response prediction methods would be to narrow the current Zone 2 boundaries and provide, by some more detailed procedure, a "go or no go" decision as to whether a given degree of community response is to be expected.

Unfortunately, as suggested by our earlier very brief review of the many factors entering into the community response picture, development of a detailed procedure which would provide predictions of specific degrees of community response for particular airport-communities appears beyond reach at this time. Of a number of factors precluding such development, several major ones should be emphasized:

a) current understanding of the linkages between the expressed response of individuals (as determined by judgment tests or personal interviews), and resulting community expressions or actions, is incomplete. Understanding of what community sociological and economic factors should enter into the prediction, and weightings to be assigned to such factors, is fragmentary.

b) community response, however categorized, involves ranges of response on several different levels of social organization. Pending development of an acceptable scale, or definition of degrees of community response, one must necessarily accept a grey area in attempting to predict a loosely defined response.

c) inherent variability in the noise stimuli, and in individual response to noise stimuli, act to contribute uncertainty in predicting community response. (Fortunately, as will be discussed in later sections of the report, we do have some indication of the variability in response these factors may produce.)

Although development of accurate predictions of specific degrees of community response to aircraft noise in individual communities does not appear feasible at this time, the guides to expected group response that are available

(exemplified by the existing prediction procedures) are extremely useful. It would be valuable, particularly to those involved in noise problems at individual airports or communities, to have a means for predicting the "boiling point," or "degree of temperature" for any particular community. However, guides or standards for nationwide use must necessarily be based on averages and procedures that can be applied equally well to both large and small communities, and to communities boasting strong or weak internal structure or economic patterns. Thus, when considering noise criteria for possible nationwide application, guidelines developed from averages may be satisfactory, provided there is understanding of the variability and degree of deviations which may be expected in individual situations.

Faced with variabilities and inconsistencies in defining either individual or community response in particular instances, we may view the prediction procedure in terms of predicting the "average" response expected from a sampling of a large group of individuals or of a large number of airport-community situations. In development of this idea, we will adopt the hypothesis that, on an average derived from a large number of samples, we may expect that as the degree of dissatisfaction with the noise environment increases and the number of individuals dissatisfied with the noise environment increases, the likelihood of observable unfavorable response by the community also will increase. We also hypothesize that there is, on the average, a nondecreasing function relating the number (or proportion) of people dissatisfied, and the likelihood of unfavorable response by a community. This relationship will not necessarily hold in any one community or any small sampling of communities, but may be observed from a very large number of samples of community response gathered from communities existing in different segments of the country. In developing this hypothesis we will define the reaction of individuals in terms of expressed judgments that are observed in formal judgment tests or obtained in field interviews in response to questions put to individuals by trained interviewers.

The existing community response prediction procedures may be reviewed in terms of the above "statistical" approach with emphasis upon problems in defining and measuring the noise stimulus, and relating such measures to expressions of individual response to aircraft noise. In making this study, we can make use of some new information concerning judgments of aircraft noise contributed by three series of tests:

a) judgments of aircraft noise on a category scale of "intrusiveness," made by 60 subjects in indoor and outdoor tests conducted at Farnborough, England in 1961.6/

b) determination of subjective annoyance in a social survey (personal interview study) conducted in neighborhoods in the vicinity of London (Heathrow) Airport in 1961.7/ This social survey was conducted in conjunction with measurements of aircraft noise and the number of flight operations during the period of the survey.

c) judgments of aircraft noise on a category scale of "acceptability," conducted near the Los Angeles International Airport in 1964, reported in detail in Part II of this report.

These judgment tests are of interest for three reasons:

1) The tests indicate the mean noise levels at which reasonably well defined descriptions of the noise, such as "objectionable," "very objectionable," etc., will be applied to the noise by groups of subjects. (Note that such agreement in descriptions of noise does not necessarily indicate similar likelihood of the subjects taking action with respect to the noise. For example, only a small, and variable, proportion of people judging a noise environment unsatisfactory would be likely to complain to authorities or enlist community action to change the noise environment.)

2) The tests also indicate the magnitude of changes in noise stimulus required to shift the mean response from one category of response to another. Thus they indicate the change in noise stimulus required to effect a definite change in subjective attitudes.

3) The tests provide an indication of the degree of variability of subjects in responding to a given noise stimulus. (Note that persons who may have similar sensitivity in distinguishing between the noisiness of two signals may hold quite different attitudes towards the noise signals or assign quite different adjectives in describing the noise.)

In the following section, the description of aircraft noise level in terms of the perceived noise level and the selection of correction factors to be applied to the noise level to obtain CNR values, incorporated in the existing community response procedures, are reviewed in light of recent relative and category judgment tests. In the succeeding section, Section IV, CNR boundary values for zones of community response are reviewed making use of information from category judgment tests and field measurements of aircraft noise.

IV. ANALYSIS OF FACTORS DETERMINING THE COMPOSITE NOISE RATING

A. Descriptions of Noise Stimulus

In the past, a relatively large number of noise descriptions have been utilized in attempting to find meaningful and compact descriptions of the noise that may be related to either individual response or community response. A summary of various descriptions of the noise which have been used at one time or another is given by Clark in Part I of FAA Report RD-64-148. From a review of the development of existing procedures for predicting community response, it appears that three parameters are most important in describing the aircraft noise environment.

1) a measure of the noise magnitude, which is related to subjective ratings of noisiness or acceptability

2) a measure of the time duration of the noise stimulus

3) a measure of the number of occurrences of the noise stimulus.

In the existing procedures, the magnitude of aircraft noise is described in terms of the maximum perceived noise level, (expressed in PNdB) occurring during a flyover. Currently, the perceived noise level is determined from octave or third-octave frequency measurements of the noise, ignoring the relative duration of the flyover signal or presence of strong pure tone components. Laboratory studies aimed at refinements of the perceived noise level scale, suggest that the relative acceptability or noisiness is determined also in part by the time duration (for relatively short time duration signals, typical of flyover noise),

and that shorter signals are less noisy than signals of longer duration and equal perceived noise level.*

With refinement of the perceived noise level calculations to include the effect of time duration, and perhaps, the strength of pure tone components, it would appear that we have a reasonably accurate scale for measuring noise magnitude that correlates well with subjective ratings of relative noisiness or acceptability. Further, it appears that additional refinement in the perceived noise level scale, if needed, can be accomplished in a quite straightforward manner by established psychoacoustic test techniques.

However, the relative judgment tests do not indicate what changes in noise levels are needed to change one's attitude towards noise, nor the degree of variability in peoples attitudes towards noise. For this type of indication, we can look at category judgment tests of aircraft noise.

The relatively large degree of variability to be found in the category judgment tests suggests that refinements in the perceived noise level scale will not lead to improved accuracy in predictions of community response to aircraft noise. Refinements in calculating perceived noise levels are of considerable value in making accurate comparisons between different aircraft operations. However, such refinements are likely to be

---

* The laboratory tests indicate that a doubling of the time duration (with duration taken as the time the noise signal remains within 10 PNdB of the maximum level) is equivalent to an increase of the noisiness of 4.5 PNdB. The reported laboratory tests were concerned with relatively short time durations -- of the order of 12 seconds or less. For significantly larger signal durations, the duration correction may lessen. This is being investigated by the FAA under Contract FA65WA-1180.

obscured by other variables when making assessments of the noise exposure in field aircraft noise situations.

B. CNR Correction for Number of Occurrences

Past experience indicates that the number of occurrences of flyover noise influences subjective response to noise. However, when we attempt to determine the effect of number of occurrences in a quantitative manner, we face a much different and much more difficult problem from developing a scale of relative acceptability of aircraft sounds.

In determining the effect of number of occurrences, we are really seeking to determine response to noise exposure over a considerable period of time. This is not easily investigated by standard laboratory tests covering relatively short time periods. Thus our best clues to the effect of number of occurrences are obtained by rather tenuous extrapolation of field noise situations, or by analysis of elaborate field survey tests.

In the current procedures for estimating community response, CNR corrections in 5 unit steps are introduced for different ranges of the number of operations occurring per day. Effectively, the CNR corrections are proportional to 10 log N, where N is the number of operations. The factor of 10 has been derived from field case histories and basic noise energy considerations.

The British social survey conducted in the vicinity of London (Heathrow) Airport offers some new evidence as to the effect of number of operations on subjective response to aircraft noise. In this study, annoyance ratings were classified with respect to the average flyover noise level in PNdB and average number of flyovers per day. In Reference 7, the data were interpreted to indicate that subjective annoyance varied with 15 log N, rather than 10 log N as assumed in developing the CNR ratings.*

---

* This factor of 15 log N is incorporated in the derivation of the "noise and number index," (NNI), where:

$$NNI = PNdB + 15 \log N - 80$$

However, an analysis of the survey data, summarized in Appendix A, shows that the correlation of noise level and number of occurrences with annoyance scores is fully as valid, in a statistical sense, for a factor of 10 log N as 15 log N. In view of this, there is no clear evidence at the present time that the current CNR correction for number of occurrences based on 10 log N should be changed.

The difference between 10 or 15 times the logarithm of the number of operations leads to a difference in CNR corrections of 5 for a ratio of 10 to 1 in the number of occurrences, or 10 for a ratio of 100 to 1 in the number of occurrences. Such a difference in the correction for the number of operations produces appreciable error only when determining the CNR ratings at airports having very few operations or very many operations per day. Assuming that the best correlation with case history experience and category judgment tests is based upon noise environments involving the order of 10 to 30 occurrences per day, appreciable error would occur only when evaluating conditions at airports having less than about one or two operations per day, or at airports where operations exceed several hundred per day.

C. <u>CNR Corrections for Time of Day</u>

In the computations of CNR ratinga in the existing prediction procedures, a +10 correction is applied to determine CNR ratings for nighttime occurrences. This correction reflects an order of magnitude estimate of the increased sensitivity of individuals to noise stimuli at nighttime. This difference in sensitivity reflects a reduction in background noise levels (resulting in an increase in the signal-to-noise ratio of the intruding aircraft noise), a shift in activities of individuals, and perhaps a difference in people's attitudes towards noise in daytime and in nighttime. Although the effects of changes in background level can be explored by systematic laboratory tests, the other possible influences cannot. Hence, information as to the size of the correction is most directly obtainable from field experience or from elaborate field survey experiments (such as the British social survey).

The British social survey study provides limited information regarding the nighttime correction. The study evidence suggested that the annoyance caused by the aircraft noise was roughly equal for daytime and for nighttime operations. It was estimated that the average noise levels in daytime were 8 PNdB greater than nighttime levels, and that the number of daytime operations were four times as many as nighttime operations. This led to the conclusion in Reference 7 that nighttime noise criteria should be about 17 NNI lower than the daytime criteria, taking into consideration a weighting for number of operations based on 15 log N. If we assume a weighting for the number of operations of 10 log N, we obtain a shift of 14 units between daytime and nighttime criteria. Thus the British results indicate that the +10 correction currently incorporated in determining CNR ratings is conservative by the order of 5 CNR units. However, in view of the assumptions and averages involved, the London social survey study can provide only a very tentative estimate of the nighttime correction. Nevertheless, the indication is that it should not be <u>less</u> than 10 units.

In investigation of many civil airport situations, it is commonly found that the high proportion of daytime operations compared to nighttime operations is such to offset the +10 correction for nighttime operations. Thus it is found that:

a) daytime CNR ratings are higher than the nighttime CNR ratings, or

b) daytime and nighttime CNR ratings are essentially equal.

An increase in the nighttime correction to +15, increasing the importance of nighttime operations in determining adverse community reaction to noise, would increase the number of cases in which nighttime ratings would exceed daytime ratings. However, field experience currently indicates few cases in which this increased correction for nighttime operations is warranted.

V. INTERPRETATION OF CATEGORY JUDGMENT TEST RESULTS

In Section III, it was indicated that the category judgment tests provide information concerning:

a) the mean noise levels at which relatively well defined descriptions of the noise will be applied by groups of subjects

b) the magnitude of change in noise stimulus required to shift from one category of subjective response to another

c) the degree of variability in subjective response to a given noise stimulus.

In this section, the category judgment tests are reviewed in terms of each of these three factors.

A. Mean Category Responses

Figures 5 and 6 present comparisons of the noise ratings, obtained from the social survey, Farnborough, and Los Angeles experiments. In Fig. 5 we have shown the ratings correlated with the outdoor perceived noise level, plus a weighting due to number of occurences equal to 10 log N. In Fig. 6 we present a similar comparison with the outdoor perceived noise level but with number of occurrences weighted in accordance to 15 log N.* To the left on each figure we show the Los Angeles acceptability scale, and to the right we show both the social survey annoyance scale and the Farnborough intrusiveness scale. (Note that, for the British scales the interval spacing between categories is not uniform.) It is evident in both Figs. 5 and 6 that the curves do not coincide. In fact, since the categories judged in the different tests are not necessarily directly comparable, there is no basic reason why the curves should form a single curve.

---

* With subtraction of 80, the horizontal scale corresponds to the NNI scale.

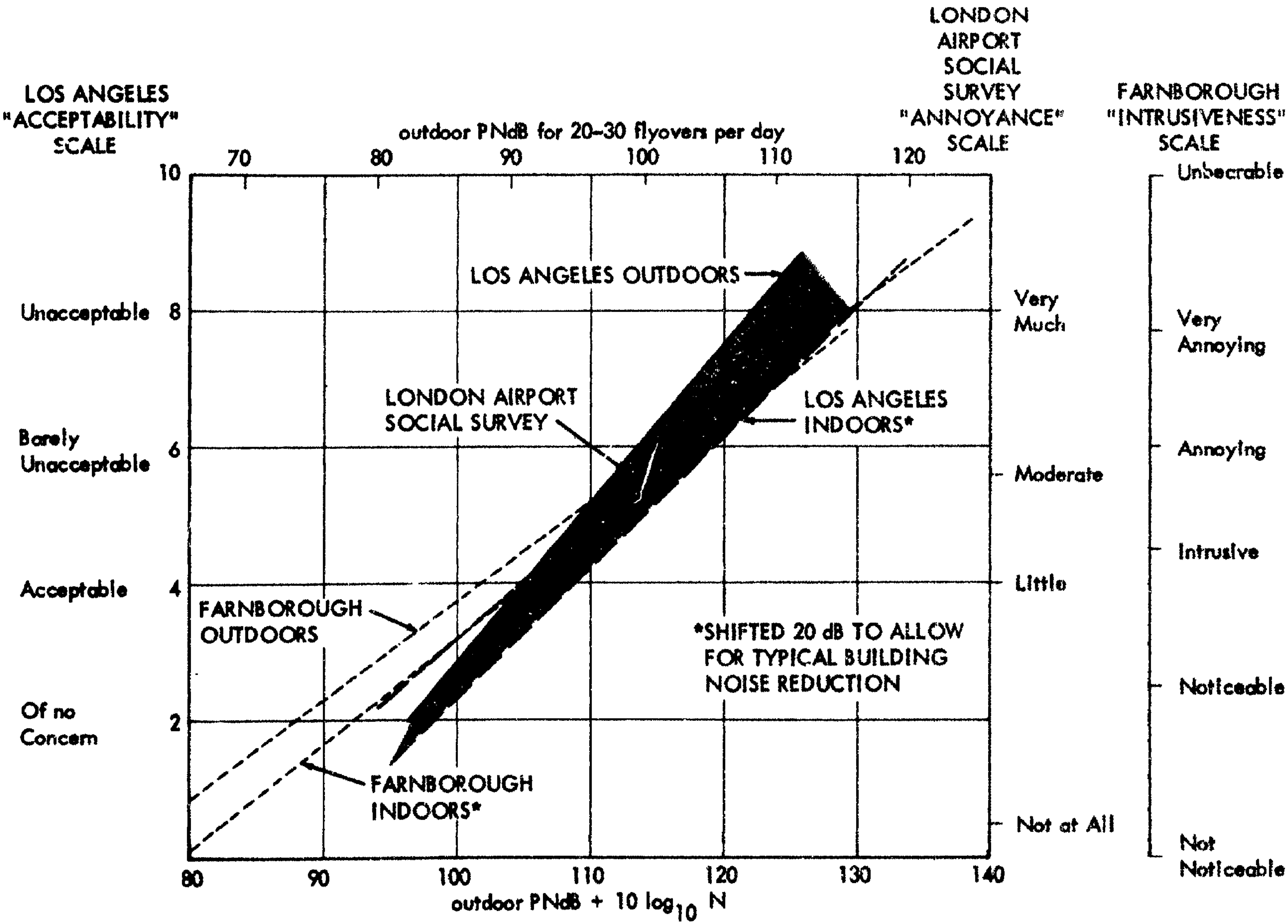


FIGURE 5. COMPARISON OF AIRCRAFT NOISE RATING SCALES (ASSUMING 10 log N WEIGHTING FOR NUMBER OF FLYOVERS)

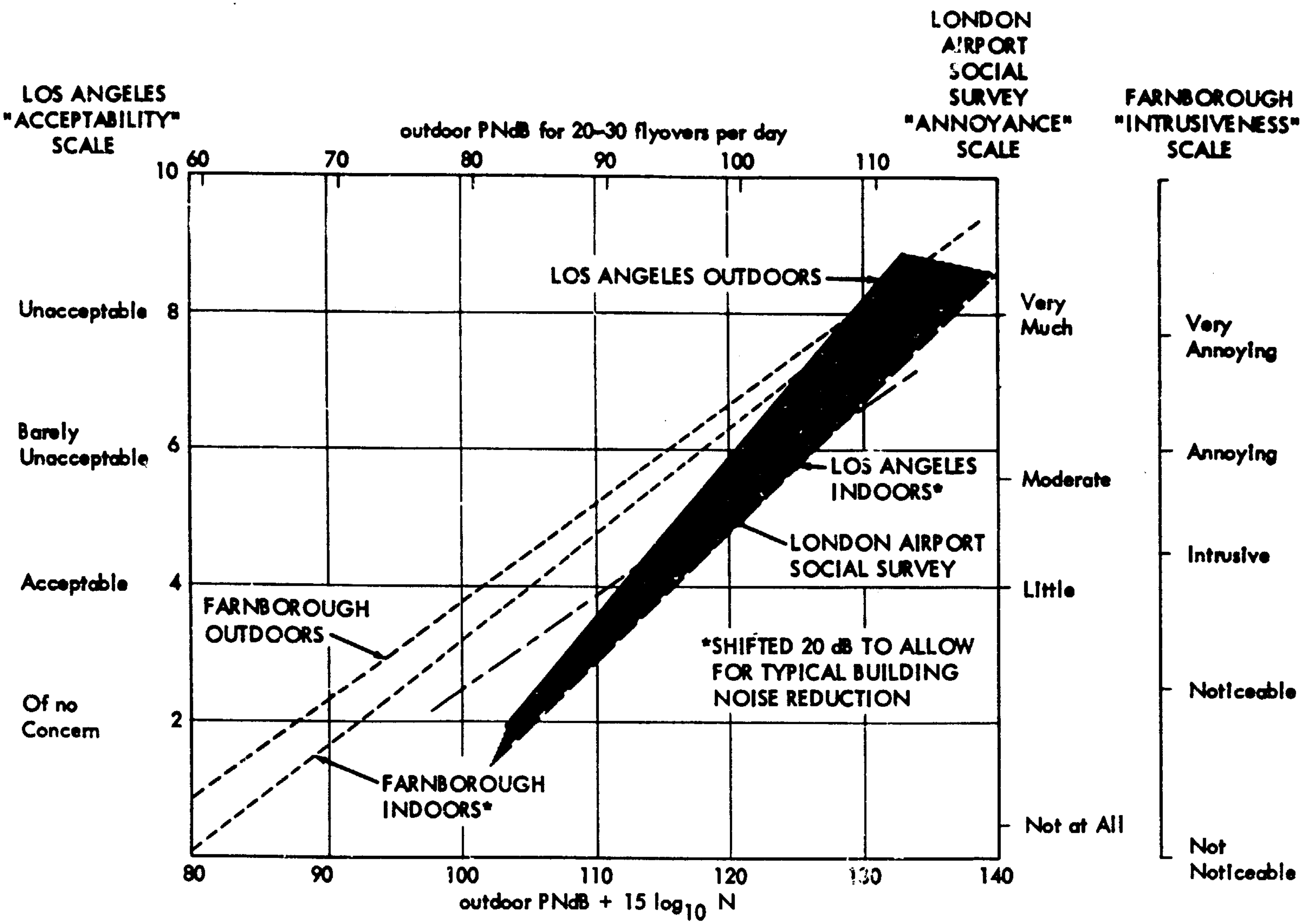


FIGURE 6. COMPARISON OF AIRCRAFT NOISE RATING SCALES (ASSUMING 15 log N WEIGHTING FOR NUMBER OF FLYOVERS)

However, it is important to note that for the various adjectives implying quite a significant degree of dissatisfaction with the noise, such as "unacceptable", "very annoying", and "very much annoyance", there is reasonably good agreement as to noise stimuli.

If we look at Fig. 5, where there is the least diversity among curves, we see that the mean judgments reach a significant degree of dissatisfaction at perceived noise levels ranging from 108 to 116 PNdB, for situations where the number of flyovers is about 20 to 30 per day. This range of values brackets the CNR rating of 115 currently set as a boundary between Zones 2 and 3 of community response in Table II. Thus, in terms of common experience gained from both field noise problems and more formal category judgments of aircraft noise, there is a reasonable concensus concerning the level of noise at which there will be widespread dissatisfaction.*

As we shall see later, because of the variability in subject judgments, there will be sizeable proportions of the subjects who judge the noise unacceptable even at noise levels considerably below the 108 to 116 PNdB range quoted above.

B. Shifts in Mean Category Responses

Table III lists the change in noise level required to produce a significant shift in mean category judgments of aircraft noise. In this table are tabulated the changes in noise exposure (PNdB +10 log N) required for

---

* It is also pertinent to note that a major conclusion of the London social survey study was that exposure to aircraft noise reached an unreasonable level in the range of 50 to 60 NNI (130 to 140 units on the horizontal scale of Fig. 6). In the context of 20 to 30 flyovers occurring per day, this NNI range is equivalent to CNR values of 109 to 119.

TABLE III

COMPARISON OF NOISE LEVEL CHANGE REQUIRED

TO SHIFT MEAN CATEGORY RATINGS BY TWO CATEGORIES

Test	Category Shift	Noise Level Increase, PNdB
Los Angeles Acceptability Scale	"Acceptable" to "Unacceptable"	17* to 21**
Farnborough Intrusiveness Scale	"Intrusive" to "Very Annoying"	20* to 22**
London Airport Annoyance Scale	"Little" to "Very Much"	23

* Outdoor Judgments

** Indoor Judgments

a mean shift in the rating of two categories for the three different judgment tests shown in Figs. 5 or 6. For the acceptability scale, a change in noise exposure of 17 to 21 PNdB was required to change the mean response rating from "acceptable" to "unacceptable". Similarly, a shift of 20 to 22 PNdB was required to change mean response from an "intrusive" to "very annoying" rating on the Farnborough intrusiveness scale. And, a shift of 23 PNdB was required to change mean response from "little" to "very much" annoyance in the London social survey study. Thus, it is evident that a shift in noise exposure of the order of 20 PNdB is required to provide a pronounced shift in mean attitudes towards aircraft noise.

C. Combined Effects of Stimulus and Response Variability

In considering the prediction procedures in terms of our "statistical" model, we can consider some of the uncertainties limiting the reliability of prediction as arising from variability introduced by differences in individual response, and variability introduced by the noise environment found in actual airport environments. The variability introduced by these factors act to create an area of "uncertainty" that may be viewed as:

1) limiting prediction accuracy of the model, or

2) describing minimum values for the change in noise environment likely to effect noticeable changes in individual or group response.

The situation may be demonstrated by means of Fig. 7. In this figure, graphs of the noise stimulus are shown along the left hand side of the figure, and resulting judgments of the noise acceptability are shown along the right side of the figure. Case A, in the upper portion of the figure, represents an idealized situation. The stimulus is distinctly defined by flyover noise levels separated in maximum values by 15 PNdB. On the corresponding right hand graph are the idealized judgment responses one might expect if all individuals characterized the noise in a similar manner.

The graphs in the middle of the figure, Case B, represent conditions typical of laboratory or field judgment tests.

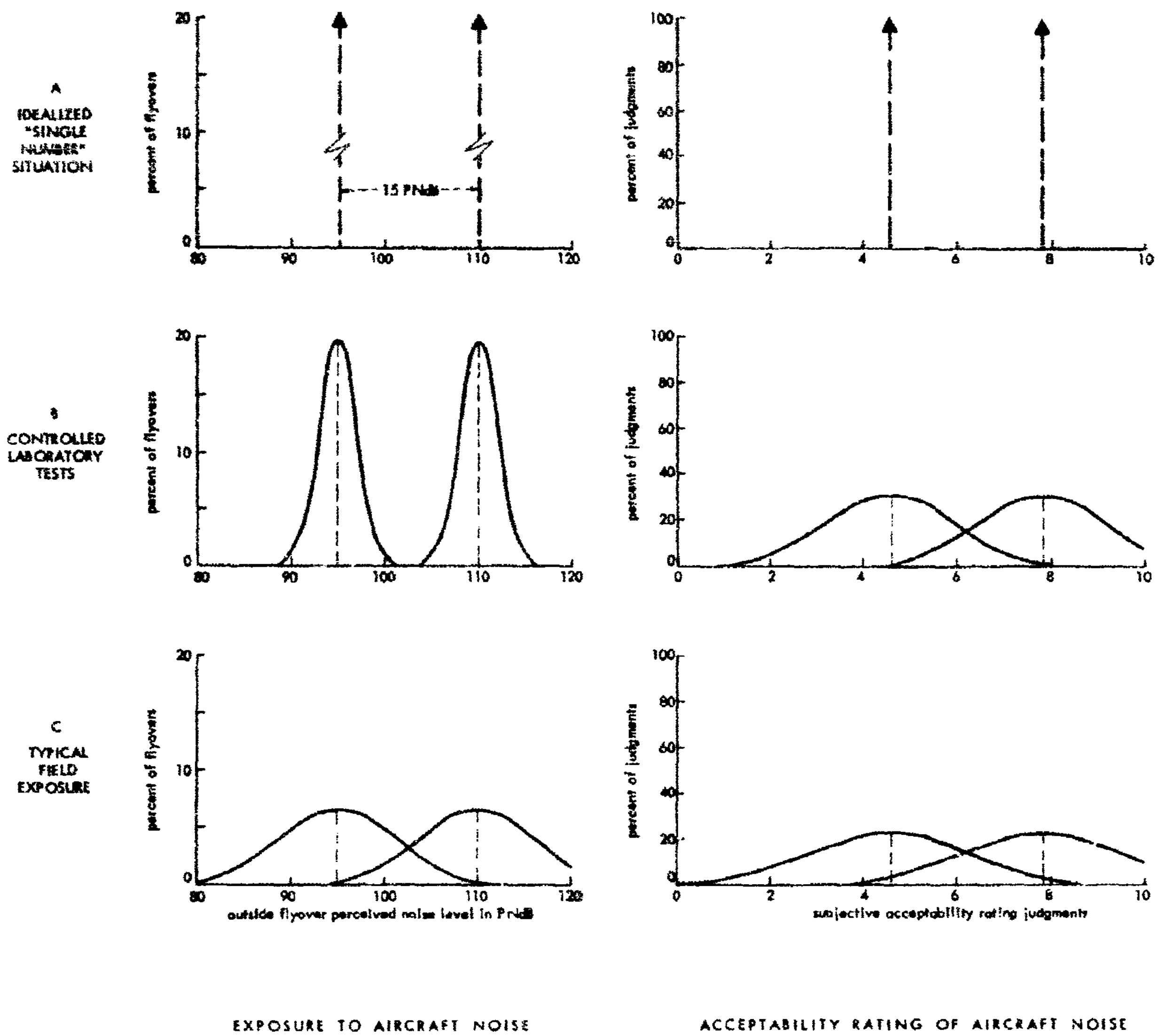


FIGURE 7. COMPARISON OF STIMULUS AND RESPONSE DISTRIBUTIONS - AIRCRAFT FLYOVER NOISE JUDGMENTS

Unlike the idealized situation, there is now some variability in the noise exposure, arising from errors in measurement and variations in the test room environment. And, unlike the idealized case, the noise judgments show considerable variability resulting in broad response curves. The curves are sufficiently broad to indicate a distinct overlapping of responses in a small percentage of cases. (The dispersion shown is based on typical results observed in the Los Angeles tests, and are similar in magnitude to those observed in some of the British tests.)

In Case C shown in the lower portion of Fig. 7, the noise exposure and expected response typical of actual field situations are depicted. The noise environment is now quite broad, encompassing a considerable range of flyover noise values. The result of this broadening in stimulus is to broaden further the expected response of individuals exposed to noise.

In Table IV, we have tabulated the change in noise levels required to institute a significant change in the proportion of people rating the noise in a given category, using measures of variability taken from various judgment tests and field noise measurements. The first row of the table lists the estimated changes in noise levels required to increase the percentage of people judging noise "unacceptable" from 10% to 50%, or from 5% to 50%. These values are based on the subject variability observed in the Los Angeles acceptability tests, and they assume no variability in noise environment. The second row lists flyover noise level changes, assuming no variability in subject response but variability in noise environment of the order encountered in field situations (6PNdB standard deviation).*

---

* See Part VI of this report for examples of the variation in flyover noise levels encountered in field measurements under major takeoff or landing flight paths.

TABLE IV

ESTIMATED INCREASE IN MEAN FLYOVER NOISE LEVELS NEEDED TO INCREASE PROPORTION OF PEOPLE JUDGING NOISE "UNACCEPTABLE" OR "VERY ANNOYING"

	Increase in PNdB for Shift in Proportion of Subjective Responses from:*	
	10% to 50%	5% to 50%
Variability in Group response[1]	8.3 PNdB	10.7 PNdB
Variability in flyover noise levels[2]	7.7	9.9
Combined variability in group response and flyover noise levels[1,2]	11.3	14.6
London Airport Social Survey[3]	15	--
London Airport Social Survey (Adjusted Est.)[4]	12	16

* Estimates are based upon normal distribution curve with standard deviations derived from experimental data

1 Based on category judgment data reported in Part II

2 Standard deviation of 6 PNdB

3 Reference 7

4 Adjusted values extracted from Reference 7 data. See text.

The third row lists the changes in flyover noise levels due to the combined effect of subject response variability and noise environment variability.

The fourth row of Table IV lists the estimated change in mean noise levels required to increase the proportion of people judging the noise "very annoying," as based upon the London Airport social survey study data. In this survey it was believed that people's response to aircraft noise and judgments of aircraft annoyance were also colored by their like or dislike of other factors in their particular neighborhood. For example, if they were well satisfied with other aspects of the neighborhood, they would tend to underrate the annoyance due to aircraft noise. If we adjust for these factors along the lines suggested in Reference 7, we get somewhat smaller estimates of the noise levels required to change the proportion of subject responses. These smaller values are indicated in the last row in Table IV.

Review of the values shown in Table IV suggests that a range in mean noise levels of 8 to 12 PNdB covers an area in which the proportion of people finding the noise unacceptable may vary from 10% to 50%. If we view this range in percentages of people judging the noise unacceptable as a "triggering" range, in which sufficient proportions of the people are likely to become dissatisfied enough to institute overt indications of "community response," then a range of 8 to 12 CNR units between "no response" to "vigorous response" categories of community response appears reasonable. With this view, therefore, a sizeable proportion of the existing 15 CNR unit spread between community response Zones 1 and 3 is due to variability in subject responses and variability in aircraft noise stimuli. Thus, we can conclude that even if we had a much fuller understanding of the linkages between individual response (as obtained in tests or interviews) and observed community reaction, there would be a considerable spread of noise stimulus in which a given degree of community response might be observed in a particular airport-community.

VI. A SUGGESTED NOISE CLASSIFICATION PROCEDURE FOR AIRCRAFT AND AIRPORTS

A. Purpose

One of the major purposes of this project has been to examine the technical possibilities for noise certification, or noise rating of aircraft. Because safety considerations are not involved, certification may be viewed in terms of a standardized rating procedure, designed to provide information about the aircraft noise characteristics that will be helpful to the aircraft operator and to others concerned with operational use of the aircraft. Thus the noise information provided by a standardized rating procedure should be in a form that would also be useful to the airport operator, airport administrator, and others concerned with community noise problems or land usage in the vicinity of airports.

This section presents a suggested method of rating aircraft noise to be applied to both aircraft and to airports. The major intended purpose of this procedure is to provide guides for the development of both aircraft and airports and to minimize noise problems arising from aircraft operations.

Most aircraft noise problems arise from the impact of aircraft noise on land areas near airports. The measured noise characteristics for a given aircraft generally mean little, in terms of a particular airport-community noise situation, except when interpreted in terms of noise exposure related to specific land areas. Thus if the aircraft development is to be guided by setting up noise rating procedures for aircraft, it is equally important that airport development also be guided by noise considerations. Therefore, we believe it is essential that a noise specification encompass development of complementary noise rating procedures which should be applied to both aircraft and to airports.

Any such rating or classification procedure will not, in itself, solve existing airport-community noise problems, particularly those noise situations at existing airports where land is highly developed in areas immediately

outside airport boundaries. However, a complementary noise classification procedure, applied to both aircraft and airports, should be helpful in guiding the design of future aircraft, the development of new airports, and the expansion of existing airports.

As previously discussed, the description of aircraft noise in terms of perceived noise level offers a quite adequate way of objectively rating aircraft noise in terms related to relative judgments of annoyance or noisiness. Refinements in current methods of calculating the perceived noise level may well be introduced in the future. However, current calculation methods are sufficiently accurate to discriminate between noise stimuli having significantly different subjective response. Thus one need not wait for ultimate refinement in descriptions of aircraft noise in order to develop useful noise rating procedures. Care should be exercised, however, to avoid placing undue emphasis on small differences in noise measurements or noise ratings.

B. Suggested Aircraft Noise Rating Procedure

The following steps outline a suggested aircraft noise rating procedure:

1) sets of standardized takeoff and landing perceived-noise-level contours should be developed for rating purposes. A minimum of three sets of contours would be needed:

   a) takeoff noise contours applicable for long-range jet transport aircraft

   b) takeoff noise contours for short-and medium-range jet aircraft (and business jet aircraft), and

   c) landing noise contours for all jet aircraft.

   Such "standard" contours can be developed from generalized noise contours, based upon current aircraft noise and performance characteristics. As an example, the generalized contours given in References 9 and 13, adjusted to conform with

current recommended air attenuation values,[14/] might be employed.

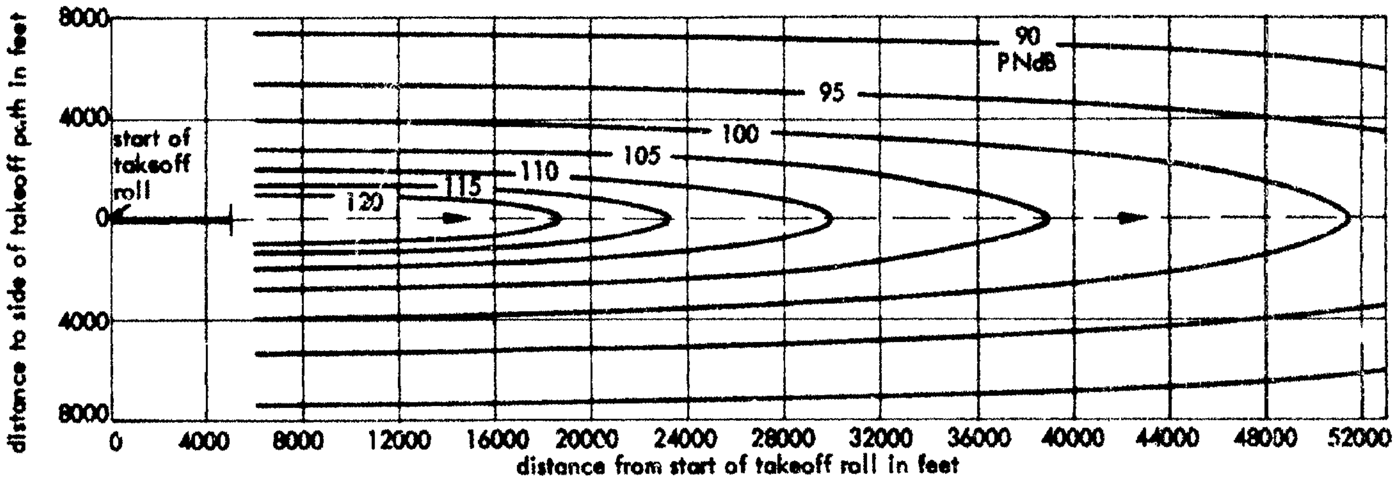
The 100-PNdB contour may be assigned as the reference contour in each standard set of contours. Ratings are to be assigned to the aircraft in terms of its degree of conformance with the reference contour. Noise contours at 5 PNdB (or, perhaps, 3 PNdB) intervals should be shown with the standard contour. Figure 9 shows the development of a set of standard contours from a set of generalized noise contours obtained from Reference 9. The upper portion of the figure shows the generalized noise contour; the lower portion, the standard contour with values assigned to the contours relative to the 100 PNdB contour.

2) based on suitable noise measurements and aircraft performance information gathered during flight tests, the aircraft manufacturer would prepare charts showing the noise contours for 100 PNdB noise levels for two or more operating conditions:

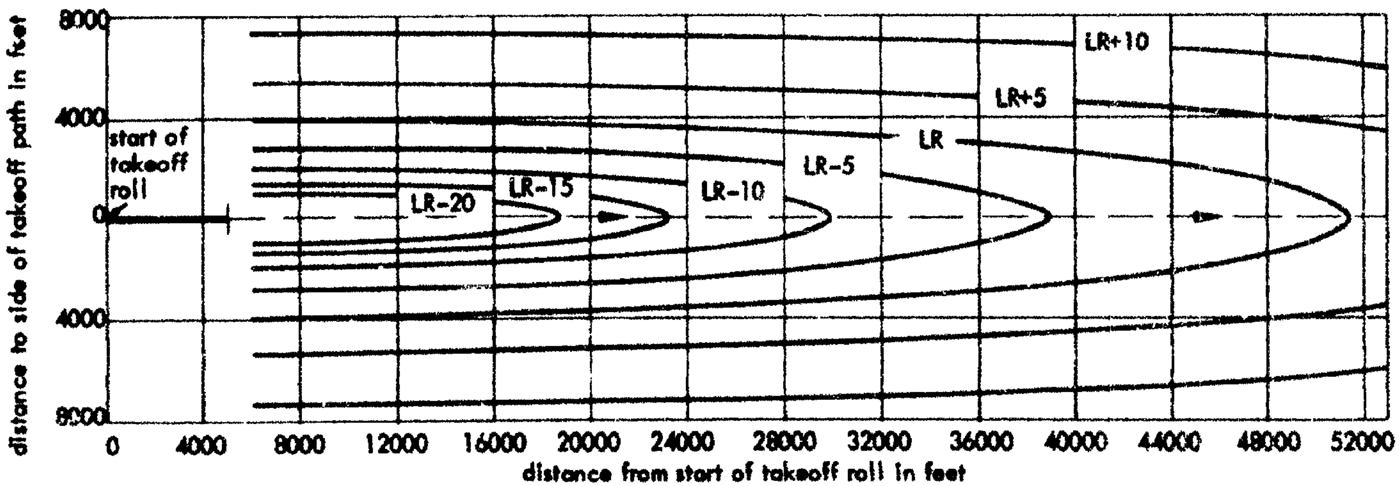
   a) takeoff at standard day conditions at maximum gross weight with no power cutback. The takeoff procedure, to be fully described by the manufacturer, should be one that can be demonstrated to be practicable for use in regular operations.

   b) a landing under standard day conditions, at maximum landing weight, following a 3° ILS glide slope. Engine power settings and procedures are to be described and demonstrated by the manufacturer.

   c) the manufacturer should be encouraged to furnish additional noise level information. For example, noise contours for takeoffs at gross weights other than maximum, and contours for takeoffs involving power cutbacks at various distances from the start of takeoff roll, would be helpful in demonstrating performance under a variety of operating conditions.



A GENERALIZED PERCEIVED NOISE LEVEL CONTOURS FOR TAKEOFFS OF LONG RANGE JET TRANSPORT AIRCRAFT



B LONG RANGE JET AIRCRAFT TAKEOFF CLASSIFICATION CONTOURS

FIGURE 8. TRANSLATION OF GENERALIZED PERCEIVED NOISE LEVEL CONTOURS TO AIRCRAFT NOISE CLASSIFICATION CONTOURS

3) the 100-PNdB contours for a particular aircraft are to be compared with the "standard" contours and ratings assigned to the particular aircraft, in terms of the degree of conformance with the reference contour.

As an example, Fig. 9 shows a comparison of the 100-PNdB noise contours generated by a hypothetical Aircraft "A" under maximum takeoff conditions with reference contours. In the example shown, the 100-PNdB contour for Aircraft "A" initially extends out to either side of the standard contour LR (reflecting a greater noise output), but does not continue out as far along the flight path as the standard contour LR (reflecting a steeper climb profile). For the example shown in Fig. 9 , Aircraft "A" would be assigned a rating of LR +5.

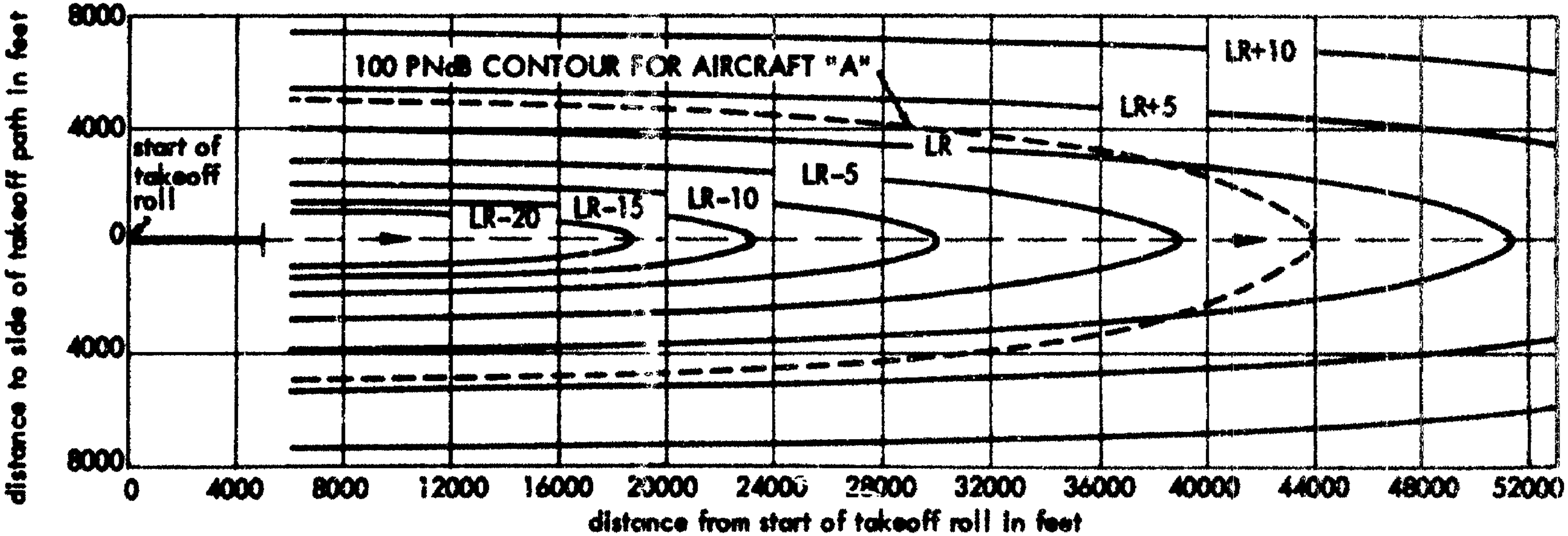
The noise characteristics of Aircraft "A" could, in a similar manner, be compared to standard contours for medium- and short-range jet aircraft and to the landing contours. Thus, as the conclusion of the rating procedure, Aircraft "A" might be assigned a set of ratings, each applicable to separate standard contours. For example, Aircraft "A" might have the following set of ratings: long-range takeoff contour, LR +5; medium-range takeoff contour, MR +10; and ILS landing contour, ILS +0.

C. Suggested Airport Noise Rating Procedure

The airport noise rating procedure would make use of the same standard contours used in rating aircraft. These contours would be applicable for each major runway. Selection of the appropriate set or sets of contours would depend on the dominating mode of operations (takeoff and/or landing) and type of traffic.

1) The standard contours would be overlaid on maps showing existing and planned land use. The land use map would depict the areas of critical land use including: residential areas, schools, libraries, churches, hospitals, and commercial establishments such as theaters, auditoriums, hotels, and motels.* In interpreting and drawing

* Part II of FAA Report RD-64-148 furnishes information as to selection of critical land uses.



LONG RANGE JET AIRCRAFT CLASSIFICATION CONTOURS

FIGURE 9. EXAMPLE SHOWING TAKEOFF NOISE CONTOUR CLASSIFICATION PROCEDURE FOR AIRCRAFT "A"

the noise contours, adjustments should be made for significant terrain features.

2) The percentage of critical land lying within the given noise contours would be determined. The noise rating contour assigned a given runway would be that contour which does not include more than, say 10%, of the land use devoted to critical noise sensitive usage. In determining the 10% allowance, land usage ordinarily regarded as noise sensitive would be removed from this classification where steps have been taken to reasonably ensure reduction of complaints due to aircraft noise. (i.e., easements have been obtained, zoning established, etc.).

It is envisioned that the airport (or runway) ratings would be used in two distinct ways. First, the rating assigned to a runway would be used purely as a summary description of the extent of land use compatibility under the takeoff or landing flight path. This description in terms of standard contours would enable one to assess rapidly the suitability of various aircraft operations from a noise standpoint. Comparison of the rating, taking into account the type of aircraft and volume of traffic actually using the runway, would provide very approximate assessment of the degree of noise problems likely to exist for that particular airport runway. Second, runway ratings could be established as a basis for qualification for funds for improvement or extension of runways, in a manner similar to other technical design criteria for airport design and construction. In this case, establishment of the desired runway contour rating applicable for a particular runway would be governed by the type and volume of air traffic expected for the airport. Assignment of contours could reasonably be based upon the airport type and traffic forecasts established in the "National Airport Plan". 15/ Selection of the appropriate contour would be based on traffic estimates using the CNR corrections for numbers of anticipated operations incorporated in Reference 9.

For qualification purposes, undeveloped land land would be removed from a critical category only where evidence is given that steps have been taken to prevent future

noise sensitive land use. Such steps might include land zoning, easements, land acquisition and/or code requirements for special noise reduction features for future building construction.

As an example, in establishing requirements for a new runway planned to handle medium- and short-range commercial jet traffic as well as business jet traffic and having an expected future volume of air transport traffic of 20 takeoffs per day, one might assign the standard medium-range takeoff noise contour with a correction of 0 (MR +0) as a technical requirement in qualifying for expansion funds. For an airport, classified in the National Airport Plan as an air carrier type, expected to handle over 100 long- and short-range jet aircraft flights per day, a rating of (LR +10) might be assigned as an objective.

D. Discussion

In discussing a suggested noise rating procedure, we have purposely omitted many technical details that will need further study and review. For example, details of measuring the noise and aircraft performance remain to be defined. However, in developing details, one may take advantage of some of the work already accomplished by national and international groups in developing standard aircraft noise measurement techniques.16,17,18/

Despite the many technical details which would have to be resolved, we believe that the long range benefits of such a complementary rating procedure would be significant. We believe that with such procedures:

a) airframe and engine manufacturers would be encouraged by their customers to obtain as advantageous a noise rating for aircraft as possible, in order to obtain the greatest degree of compatibility with existing airports and runways.

b) airports would be encouraged to instigate land planning studies and investigate methods of working with various local governments in

developing compatible land use plans.

c) institution of a noise rating procedure for runways would ensure that, as airports are developed and extended, and as airport capabilities increase in terms of size and number of aircraft to be handled, the aircraft noise problem would also receive appropriate consideration.

VII. CONCLUSIONS

1) Development of procedures for accurately predicting degrees of community response in particular airport community situations is not feasible at this time because of:

a) unknowns in defining and evaluating the influence of the multitude of sociological and economic factors, and the imperfect understanding of the decision-making processes in communities.

b) lack of development of an explicit scale for rating overt "community response."

c) uncertainties in response introduced by variability in noise stimuli and in individual reactions to the noise stimuli.

2) Current empirical methods for predicting community response in residential areas to aircraft noise (see Ref. 7) provide useful guides to predicting "typical" response expected in a sampling of a large number of communities. However, such methods may fail to provide a reliable indication of the degree of community response in particular communities.

3) The current community prediction procedures specify a 15 PNdB range of noise levels (or CNR values) separating levels at which "no response" and "severe response" can be quite confidently predicted. Two factors contributing to this range of noise levels, or "grey" area, are the variability in noise exposure observed in most actual airport situations and the variability among subjective ratings of noise acceptability.

4) Study of the variability in people's judgments of the acceptability of aircraft noise on a category scale shows that the degree of correlation of the perceived noise level scale with subjective judgments of aircraft noise is not a limiting factor in developing improved prediction procedures. Variability introduced by differences among subjects and lack of subject repeatability is equal to or greater than the variability due to lack of correspondence between the perceived noise level scale and subjective noise judgments. Improvements

in the correlation of perceived noise level ratings with subjective judgments is certainly desirable from the standpoint of comparing one aircraft or one flight procedure with another. However, such refinements will not appreciably increase accuracy in predicting group or community response to aircraft noise in actual field situations.

5) Review of the Composite Noise Rating (CNR) zone limits and the correction factors incorporated in the current prediction procedures on the basis of results of recent category judgments of aircraft noise shows that:

a) in the context of the order of 20 to 30 flyovers occurring per day, there is substantial agreement among the different judgment tests that noise levels of 110 to 115 PNdB represent noise exposure at which large segments of the population would judge the noise as "unacceptable" or "very annoying," indicating severe dissatisfaction with the noise. These judgment tests are in agreement with the CNR boundary value of 115, currently indicating the level at which "severe response" may be expected in community situations.

b) analysis of the London Airport social survey study data indicates that current corrections for number of operations and nighttime operations incorporated in existing procedures may be somewhat conservative. However the evidence does not appear sufficient to introduce a change at this time.

6) Current methods of rating aircraft noise objectively using the perceived noise level scale, and of predicting the noise environment resulting from aircraft operations, are sufficiently advanced to be useful in setting standards for rating aircraft noise. However, since aircraft noise characteristics for takeoff and landing operations are meaningful only when interpreted in terms of noise exposure in land areas around airports, rating procedures should be developed in a complimentary manner for both aircraft and for airports. A complimentary noise classification

procedure applied to both aircraft and airports should be helpful in guiding the design of future aircraft, the development of new airports and the expansion of existing airports. It would not, in itself, solve existing airport-community noise problems.

REFERENCES

1. FAA Report RD-64-148 "Analysis of Community and Airport Relationships/Noise Abatement -Work Accomplishments, May 1963 through April 1964" (December 1964) Prepared by Bolt Beranek and Newman, Inc. under FAA Contract No. FA-WA-4409

2. K. D. Kryter "Scaling Human Reactions to the Sound from Aircraft" - J. Acoust. Soc. Am., 31 1415-1429, (1959).

3. K. D. Kryter, K. S. Pearsons "Judgement Tests of the Sound from Piston, Turbojet and Turbofan Aircraft", Sound, 1, 24-31 (Mar. - Apr. 1962).

4. K. D. Kryter, K. S. Pearsons "Some Effects of Spectral Content and Duration on Perceived Noise Level" - J. Acoust. Soc. Am., 35, 866-883 (1963).

5. C. H. G. Mills, D. W. Robinson "The Subjective Rating of Motor Vehicle Noise , Appendix IX, Noise, Final Report Committee on the Problem of Noise, July 1963, HMSO (London).

6. D. W. Robinson, J. M. Bowsher, W. C. Copeland "On Judging the Noise from Aircraft in Flight", Acustica, 13, 324-330 (1963).

7. "Social Survey in the Vicinity of London (Heathrow) Airport", Appendix XI, Noise, Final Report, HMSO, London (July 1963).

8. P. N. Borsky "Community Reactions to Air Force Noise", WADD TR 60-689 (March 1961).

9. Bolt, Beranek and Newman Tech. Report "Land Use Planning Relating to Aircraft Noise", published by FAA (Oct. 1964). Also published by the Dept. of Defense as AFM 86-5, TM 5-365, NAVDOCKS P-98 "Land Use Planning with Respect to Aircraft Noise".

10. Rosenblith, W. A., K. N. Stevens, et al, "Handbook of Acoustic Noise Control, Vol. II, Noise and Man," WADC TR 52-204, pp. 179-200 (June 1953).

11. Stevens, K. N., W. A. Rosenblith, R. H. Bolt, "A Community's Reaction to Noise: Can It Be Forecase?", NOISE Control, 1, No. 1, 63-71 (Jan. 1955).

12. Stevens, K. N., A. C. Pietrasanta, et al, "Procedures For Estimating Noise Exposure and Resulting Community Reaction From Air Base Operations," WADC TN 57-10 (April 1957).

13. D. E. Bishop "Noise Contours for Short and Medium-Range Transport Aircraft and Business Aircraft", FAA Tech. Report ADS-35 (March 1965).

14. SAE ARP 866 "Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise" (1964).

15. FAA, "National Airport Plan, Requirements for Fiscal Years 1966-1970" (1965).

16. SAE ARP 865 "Definitions and Procedures for Computing the Perceived Noise Level of Aircraft Noise" (1964).

17. A. L. McPike "Recommended Practices for Use in the Measurement and Evaluation of Aircraft Neighborhood Noise Levels", SAE Preprint 650216, Nat. Aeron. Mtg., April 1965.

18. ISO/TC 43 (Secretariat-206) "Secretariat Proposal for a Procedure for Measurement and Description of Aircraft Noise in the Vicinity of an Airport".

19. W. J. Dixon, F. J. Massey, Jr., "Introduction to Statistical Analysis", McGraw-Hill Book Co., Inc., New York (1957), Chap. 11.

APPENDIX A

STATISTICAL ANALYSIS OF LONDON AIRPORT SOCIAL SURVEY DATA

In Reference 7, annoyance ratings for some 1731 people interviewed in the vicinity of London Airport were classified with respect to the average noise level and average number of aircraft flights per day. It was reported that the average annoyance rating varied almost linearily with the sum of the average noise level in PNdB and 15 log N, where N is the number of flights per day. This analysis led to the development of the "noise and number index" (NNI), where:

$$NNI = PNdB_{ave} + 15 \log N - 80$$

In our analysis of the annoyance data, using Table II of Reference 7, we compared the linear correlation of annoyance scores with noise levels plus weightings of the number of flyovers proportional to 10 log N as well as 15 log N. In making this correlation, we assumed a linear relationship between the annoyance ratings and the measure of noise level and number of flyovers. In fitting a straight line to the data, we assumed a best fit was obtained when the sum of the squared deviations of the observed annoyance ratings from the prediction line was at a minimum. This is a classical case of computing the <u>linear regression</u> of one variable.[19]

We assumed that the usefulness of an objective noise measure to predict the subjective annoyance can be estimated from the <u>correlation coefficient</u>. If the regression line estimated the reaction perfectly, the correlation coefficient would have a value of 1. If the regression line were perfectly useless as an estimator, the correlation coefficient would be zero. Thus, the correlation coefficient is a measure of the usefulness of one measure being able to predict the other.

We assumed that an indication of the reliability of the experiment of the correlation can be estimated by computing <u>confidence limits</u> for the correlation coefficient. Thus by statistical means, we can compute

for any degree of confidence, i.e., 80%, 90%, or 95%, the range or confidence interval within which we would expect the coefficient to lie if the experiment were repeated many times. In our study we chose the 95% level, or that equivalent to about two standard deviations about the mean value. By this we imply that, if the experiment were repeated a large number of times, we would expect that 95% of the time the correlation coefficient would be within the interval specified by the confidence limits.

Table A-I shows the correlation coefficient and the confidence intervals for the two correlations of noise and number of flyovers with annoyance scores. There is very little difference in correlation coefficients and, further, the confidence limits for the correlation coefficients practically coincide. Thus we conclude that there is no significant difference (i.e., no indication from the data that one weighting of the number of flyovers is better than the other weighting) between the two weightings assigned to the number of flyovers, 10 log N and 15 log N.

We may also note that the correlation coefficients are considerably smaller than 1.0 indicating quite large uncertainty in either of the two noise measures in predicting average annoyance ratings.

TABLE A-I

COMPARISON OF LINEAR CORRELATIONS OF OBJECTIVE MEASURES OF NOISE EXPOSURE TO SUBJECTIVE ANNOYANCE RATINGS-LONDON AIRPORT SOCIAL SURVEY

Objective Measure*	Correlation Coefficient	95% Confidence Limits
PNdB + 10 log n	0.457	0.42 to 0.50
PNdB + 15 log n	0.463	0.43 to 0.50

* n is the number of aircraft per day

FINAL REPORT

Contract No. FA-WA-4409

SRDS Report No. RD-65-130

Project 430-001-01R

PART II

JUDGMENTS OF THE RELATIVE AND ABSOLUTE ACCEPTABILITY OF ACTUAL AND RECORDED AIRCRAFT NOISE

December 1965

Prepared By

Dwight E. Bishop

BOLT BERANEK AND NEWMAN INC.
15808 Wyandotte Street
Van Nuys, California 91406

ABSTRACT

In separate tests, fifty subjects judged the relative and absolute acceptability or noise produced by actual aircraft flyovers and recorded flyover signals. Actual flyover noise judgments were made at both indoor and outdoor locations; recorded flyover signals were judged indoors. Most subjects judged both approach noise and takeoff noise. A majority of the flyover signals were produced by jet aircraft although a few propeller aircraft were included in the tests. Judgments were compared with maximum flyover noise levels expressed in PNdB.

Absolute judgments were made using a category scale of acceptability. Correlation of these acceptability scores with flyover noise levels showed little difference in ratings for approach and takeoff noise, or for actual and recorded noise signals. However, a shift in ratings occurred between outside and inside judgments similar in magnitude to that observed in earlier British tests. The flyover noise level for a median rating of "unacceptable" was approximately 95 PNdB for inside judgments; for outside judgments the level was 107 PNdB.

Results of the relative judgment tests also showed little difference in judgments of takeoff and approach noises, or live and recorded signals. Results of both outdoor and indoor judgments indicated that a change of approximately 16 PNdB was required for a doubling (or halving) of the acceptability rating, in contrast to the 10 PNdB assumed in developing the perceived noise level scale.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

APPENDICES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

I. INTRODUCTION

Considerable work has been done in the laboratory on judging the relative acceptability or noisiness of noise produced by aircraft.[1,2,3] Indeed, the concept of expressing the relative noisiness of a complex sound in terms of a perceived noise level has stemmed from interest in evaluating aircraft noise.[4] However, in very few experiments have subjects judged noise from actual aircraft flyovers rather than recorded flyover noise signals. And, to our knowledge, no work has been reported which compares judgments of actual flyover signals and recorded flyover signals rated by the same group of subjects.

To date, most studies have been concerned with developing or comparing scales for judging the relative acceptability or noisiness of aircraft sounds. Little effort has been devoted in this country towards exploring the possibility that people can ascribe an absolute scale of acceptability for aircraft noise. Recent British work in which subjects rated the noise of motor vehicles and of aircraft in terms of various "intrusiveness" and "noisiness" scales suggests that such acceptability scales can be developed.[5,6,7] Furthermore the British tests suggest that such scales can be reasonably well correlated with existing objective methods of rating noise.

The primary purposes of the judgment tests described in this report were to:

1) Determine if there were significant differences in the judgment of relative noisiness between noise produced by actual aircraft flyovers and by tape recordings of aircraft flyover noise.

2) Investigate the feasibility of establishing an absolute scale of acceptability for noise from aircraft flyovers.

To accomplish these objectives, groups of subjects were assembled at two test sites near the Los Angeles International Airport. One site, a furnished apartment, was

exposed to noise from frequent aircraft takeoffs; the other site, a furnished house, was exposed to noise from frequent aircraft approaches. In a series of tests, the subjects were asked to rate the noise from actual aircraft flyovers and recorded aircraft flyovers, both on a relative scale and on an absolute (category) scale of acceptability. Judgments of actual flyovers were made both inside and outside the test buildings; judgments of recorded noise were made inside the buildings. Most of the flyovers were by commercial jet (turbojet and turbofan) transport aircraft; however, a few judgments were made of noise from propeller transport aircraft.

The aircraft noise signals were recorded during the test sessions and later analyzed in terms of the maximum perceived noise level occurring during the flyovers. The scores from the several different judgment tests were then compared and correlated with these maximum perceived noise levels.

Most subjects judged noise from both aircraft takeoffs and aircraft approaches. Thus, the test results also provide an indication of the adequacy of the perceived noise level, calculated only from the maximum flyover level, to rate subjective responses to both approach noise and takeoff noise. This is of particular interest since these noises have quite different time durations and pure tone content.

The following section of the report describes the tests and the test procedures. The test results are summarized in Sections III and IV; conclusions and recommendations are presented in Sections V and VI. Noise measurement instrumentation and the noise measurement and analysis procedures are described in Appendix A; samples of test instructions and test schedules are given in Appendix B.

II. DESCRIPTION OF TESTS

A. Location

Most judgment tests of aircraft noise have been conducted in the laboratory or under relatively closely controlled conditions far removed from the home atmosphere in which most people are likely to experience aircraft noise. In the current tests a furnished apartment and a furnished house were selected for the test sites to simulate a home atmosphere and to approach test conditions not far removed from those encountered in the home or in informal social gatherings.

Figure 1 shows the location of the two test sites and their relationship to the runways at the Los Angeles International Airport. Site A, a furnished apartment, was located south of the major departure path from Runway 25L at Los Angeles International Airport. Site B, a furnished house, was located under the approach path for Runway 25L, the major instrument landing runway at the airport. Both the apartment and the house were located in residential areas and were outfitted with ordinary home furnishings. Three tests were conducted simultaneously at each test site, with groups of subjects placed in the living room, in a bedroom and out of doors. Also shown in Fig. 1 are approximate noise contours showing the typical maximum perceived noise levels which might be expected during operation of a four engine turbojet transport from Runway 25L.*

B. Noise Environment

The maximum noise level occurring during each flyover was measured in the living room, bedroom and outdoors at the test sites. (Appendix A discusses the noise measurement

---

* The contours have been extracted from those given in Reference 8.

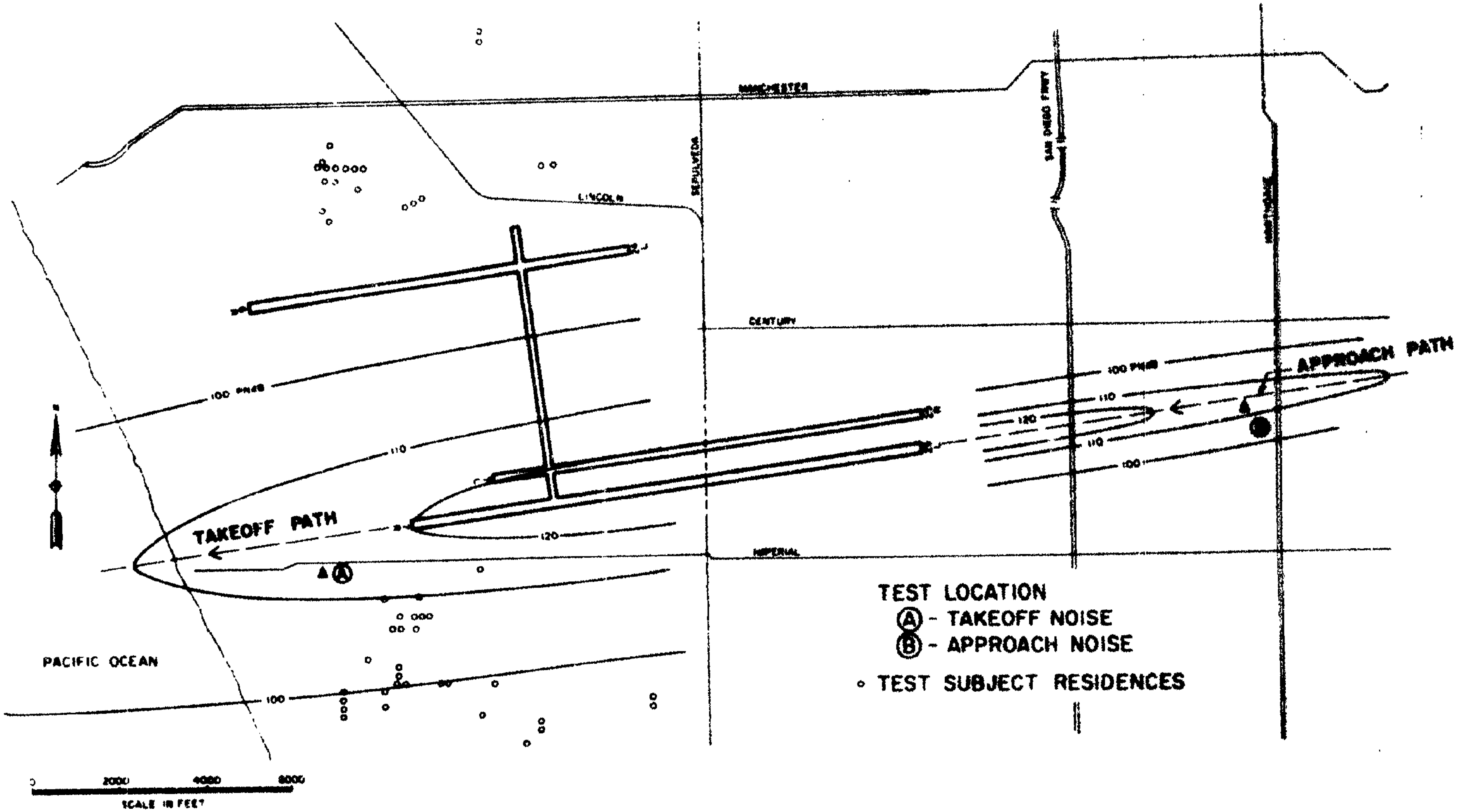


FIGURE I. LOCATION OF TEST SITES AND TEST SUBJECT RESIDENCES

and analysis procedures.) Figures 2 and 3 show the distribution of noise levels observed during the judgment tests. Separate distributions of noise levels are shown for jet (turbojet and turbofan) aircraft and for propeller (piston and turbine) aircraft. The arrows along the abscissa in each graph indicate the mean flyover noise level.

In these figures and throughout the report noise levels are measured in terms of the perceived noise level, expressed in PNdB. As described in Reference 1-4, the perceived noise level has been developed to rate aircraft sounds in a manner consistent with listener judgments of the relative noisiness or acceptability of the sounds. The perceived noise level is calculated from objective measurements of the noise. The calculations follow closely the concepts and procedures developed by Stevens for calculations of loudness level.[13,14]

Table I lists the mean flyover noise levels and the calculated standard deviation for the noise measurements. Also shown are the upper and lower quartile limits defining the range for 50% of the flyovers.*

---

* The spread, dispersion or variability of data is indicated in this report by either of two measures. The most fundamental measure is the standard deviation. The standard deviation is the square root of the variance. The variance can be defined as the sum of the squares of the deviations of observations from the mean (average) value, divided by one less than the total number of observations. For a large sample the variance approaches the mean square of the deviations. Consequently, for a large sample, the standard deviation approaches the root-mean-square (rms) deviation.

In a number of the figures and tables, we have chosen to show the spread of data by showing upper and lower quartile limits (75th and 25th percentile limits, respectively). These limits show the range for the centermost 50% of the data (semiquartile range). For a large sample of observations, having a normal distribution, there is a fixed relationship between the semiquartile limits and the standard deviation (the semiquartile range equals 1.35 standard deviations). For small samples, the relationship between standard deviation and semiquartile limits will vary from sample to sample.

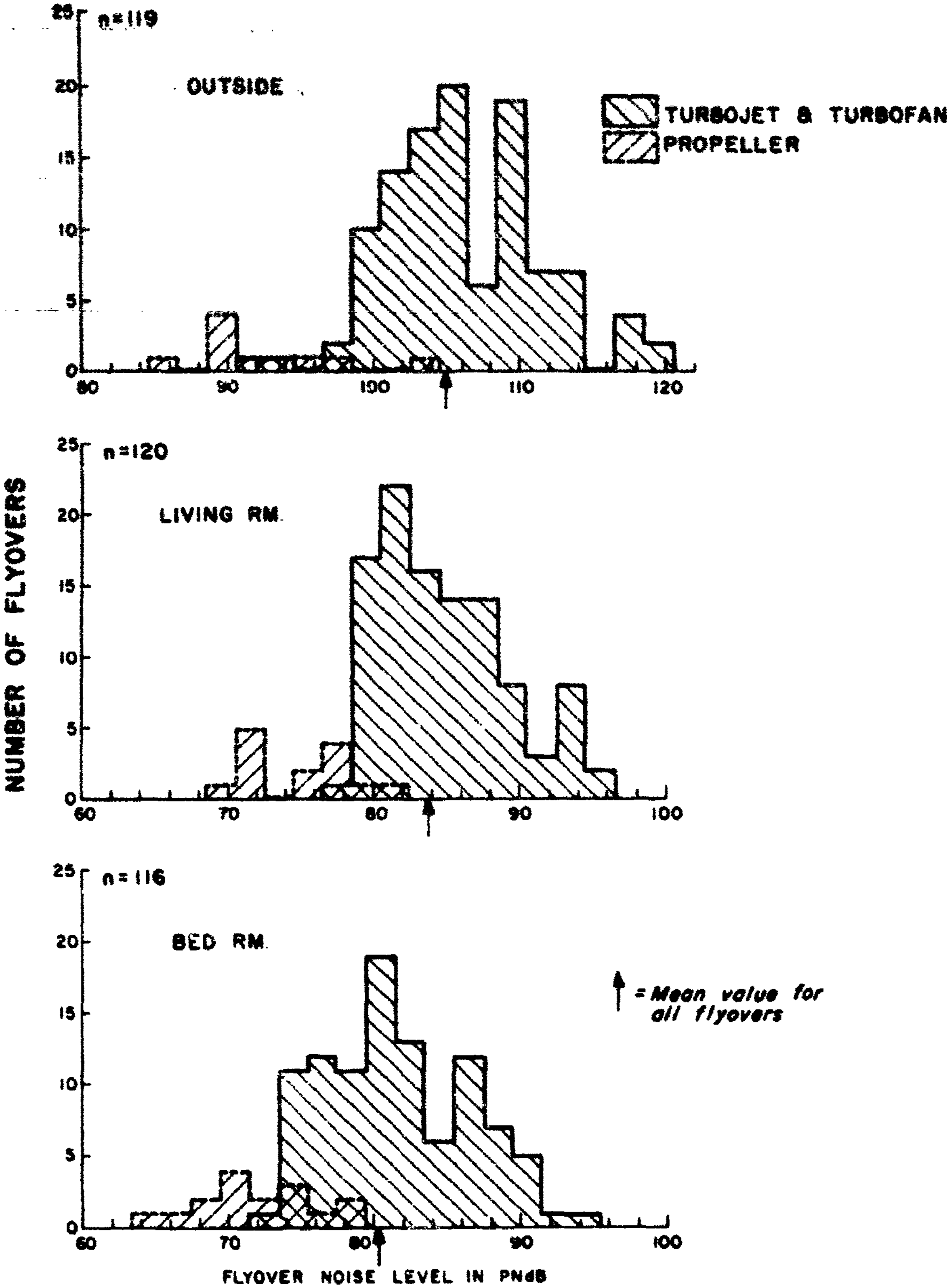


FIGURE 2. HISTOGRAM OF TAKEOFF NOISE LEVELS

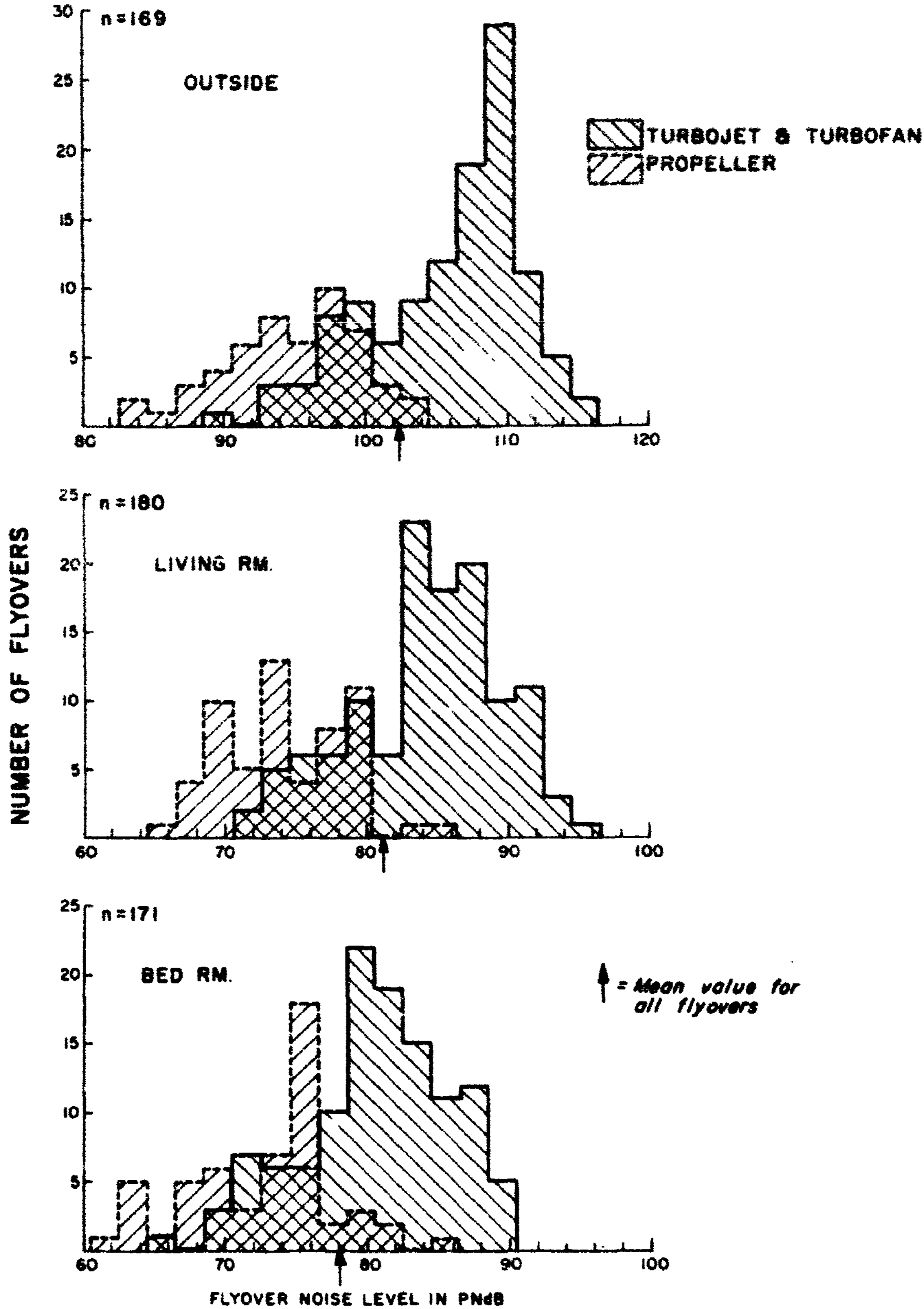


FIGURE 3. HISTOGRAM OF APPROACH NOISE LEVELS

TABLE I

SUMMARY TABULATION OF MAXIMUM NOISE LEVELS
OBSERVED DURING AIRCRAFT FLYOVERS

Type of Noise Signal	Observed	No. of Flyovers Measured	FLYOVER NOISE LEVELS, PNdB			
			Mean Value	Standard Deviation	Quartile Limits Lower	Quartile Limits Upper
Takeoff	Outside	119	104.9	6.4	102.0	109.9
	Living Room	120	83.8	5.4	80.9	87.9
	Bedroom	116	81.4	6.0	77.6	84.3
Approach	Outside	169	102.4	7.3	97.6	109.3
	Living Room	180	81.0	6.9	76	87.1
	Bedroom	171	78.1	6.4	74.7	83.2

From the table, we note that 50% of the actual flyover noise levels fell within a rather limited dynamic range, varying from 7 to 12 PNdB for the different tests. This concentration of stimuli (a consequence of exposure to flyover noise at only two test sites) may have limited accuracy in determining judgments at extremes of the dynamic range.

Table II shows the mean noise reduction values for the test rooms, determined from a sampling of the differences between individual sets of outdoor and indoor measurements. The mean values do not vary much among the rooms, all falling within the range of 21 to 24 PNdB. These are moderate values of noise reduction, expected on the basis of the conventional lightweight construction of the test buildings* and the fact that each of the test rooms had at least one exterior wall with windows which were directly exposed to the flyover noise.

One should not expect the noise reduction expressed as a difference in perceived noise levels to be a fixed value, since it will vary with the absolute level and spectrum shape of the exciting noise spectrum, the aircraft noise radiation pattern and the orientation of the aircraft flight path with respect to the test building. Table II also lists the standard deviation for the noise reduction measurements, providing an indication of the variation in noise reduction with individual flyovers. Thus for the apartment bedroom, having a sample standard deviation, s,

---

* The apartment (Site A in Figure 1) was on the upper floor of a two-story stucco on wood frame building, approximately 15 years old. The house (Site B) was a single-story wood frame building with wood siding. It was perhaps 30 years old.

See Part IV of this report for an extended discussion of building noise reduction.

TABLE II

NOISE REDUCTION OF TEST ROOMS

Type of Noise Signal	Room	No. of Measurements	Noise Reduction PNdB	
			Mean Value	Standard Deviation
Takeoff	Living Room	39	20.9	3.4
	Bedroom	39	24.1	3.0
Approach	Living Room	46	22.1	2.6
	Bedroom	46	23.8	4.2

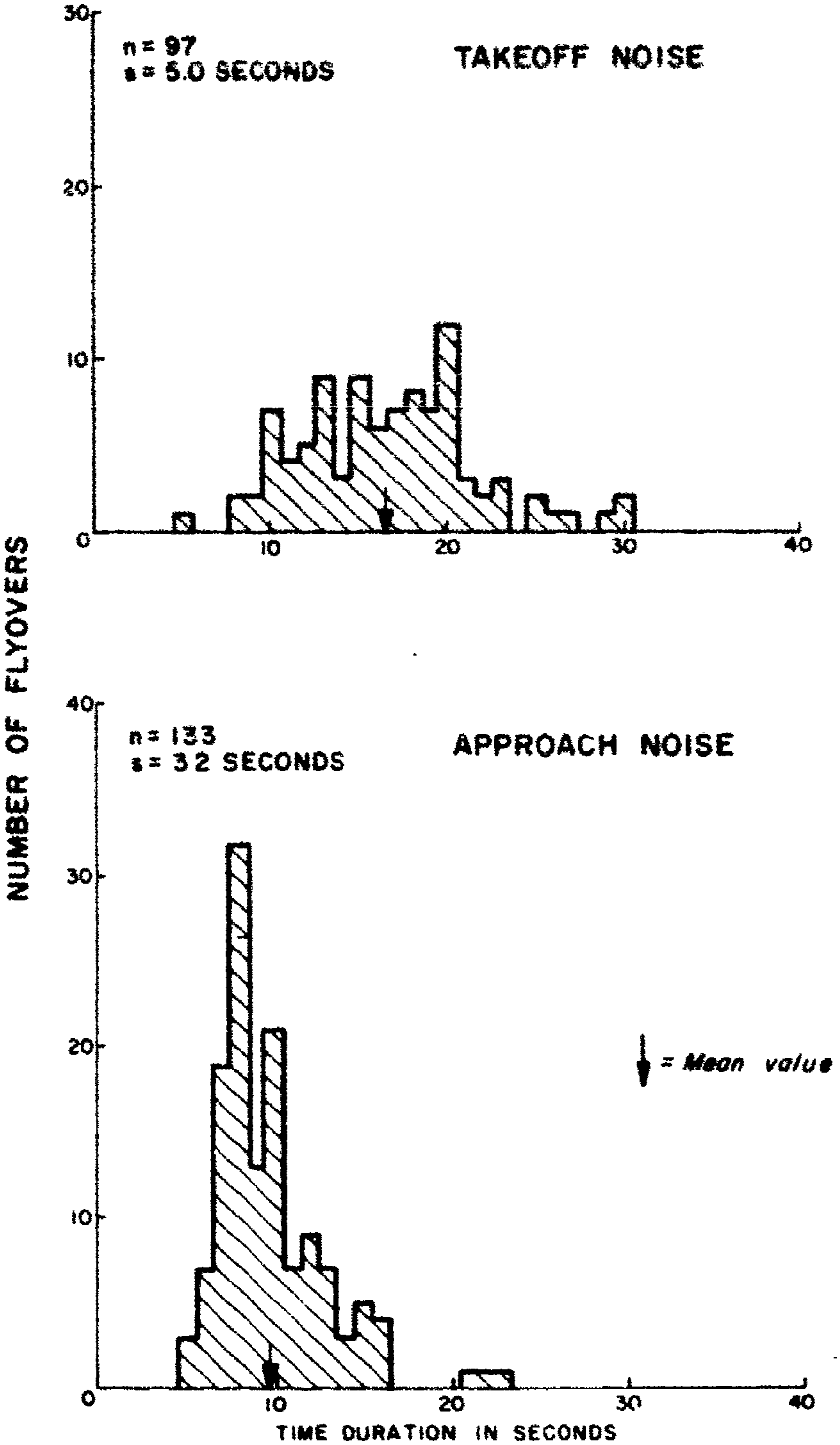
of 3.0 PNdB, one may estimate that the noise reduction for 90 percent of the flyovers will fall within ±5 PNdB (±1.65 s) of the mean noise reduction value.

To obtain a measure of the differences in time duration of takeoff noise compared to approach noise, noise records in the form of graphic level charts were examined to determine the approximate duration of the noise signals within 10 PNdB of their maximum value.* Results of this study are indicated in Fig. 4. In this figure the distribution for time durations are shown for takeoff flyovers and for approach flyovers (propeller and jet aircraft) measured out-of-doors.**

---

* A sampling of inside and outside flyover records showed no significant difference in time durations, hence the values shown in Fig. 4 also approximate the durations for the flyovers judged indoors.

** This is a measure of time duration frequently used in laboratory3/ and field investigations. See Part V of this report for further discussion of aircraft flyover noise durations.



Note: The duration is defined as the length of time that the noise signal is within 10 PNdB of the maximum level.

FIGURE 4. COMPARISON OF THE TIME DURATIONS OF TAKEOFF AND APPROACH FLYOVERS - MEASURED OUTDOORS

From the figure it is apparent that the duration of take-off flyovers spread over a considerable range, from less than 10 seconds to over 30 seconds. The mean time duration was about 16 seconds. The approach flyovers were generally considerably shorter with a mean time of 10 seconds; here, the range of time durations extended from about 4 seconds to over 20 seconds.

C. Test Subjects

The test subjects employed in many previous laboratory noise judgment tests have been college students or adults having varied backgrounds, training and experience. A conclusion from these tests was that judgments of the relative acceptability of noise signals were not significantly affected by the previous noise exposure history or training of the test subjects. This conclusion, however, may not be valid in the testing of an absolute subjective judgment scale. In fact it is probably not unreasonable to expect relatively large differences in subjective response to aircraft noise between those who have been continually exposed to aircraft noise for a number of years and those who have little exposure to aircraft noise.

The number of subjects who could be tested was not large enough to permit exploration of possible differences in absolute rating scales for many different groupings of people. Thus, selection of subjects was purposely limited to those who were familiar with aircraft noise and who could reasonably be described as having been exposed to moderate levels of aircraft noise for a considerable period of time. Such selection was accomplished by employing subjects who lived in two residential areas in the vicinity of Los Angeles International Airport. These areas, located to either side of the major runways, are exposed to moderate levels of noise from aircraft in flight and to noise from ground runups. However, neither of the areas lies directly under major flight paths. Figure 1 shows the location of the homes of the subjects who participated in the judgment tests.

A total of 55 subjects, ranging in age from 20 to 55 years, participated in the tests. Omitting the scores of five subjects whose audiograms showed greater than normal hearing losses,9/ judgments of 50 subjects were scored in the test analysis.

The subjects were asked to fill out a questionnaire prior to the initiation of the test. (A copy of the questionnaire is included in Appendix B.) The distribution of replies to some of the questions is shown in Fig. 5. This figure shows the distribution of subjects' ages, their length of residence, the number of times per day they acknowledged being aware of aircraft flyover noise and their rating of the average noise conditions in their homes. As can be seen from the Fig. 5, there was a rather equal distribution among the various age groups from 20 to 55. A near-equal distribution of men and women occurred in the age groups 20-29 years and 50-55 years; however, women greatly outnumbered men in the age groups of 30-39 years and 40-49 years. It is interesting to note that in rating the average noise heard in their homes, the most frequent choice was "moderately noisy" and no one rated his home as "extremely noisy".

D. Description of Tests

Three different sets of test instructions were employed in the experiments. Tests Nos. 1 and 2 called for judgments of the relative acceptability of aircraft flyover noise. Test No. 3 called for absolute (category) judgments of the acceptability of aircraft noise. Instructions and sample work sheets for these tests are given in Appendix B.

In Test No. 1, conducted only in the living room, subjects were given the following instructions:

> Prior to the following test, you will hear a tape recording of an aircraft flyover. Please assign the number 100 to it and mark it on your answer sheet in the space labeled "Recording". At some

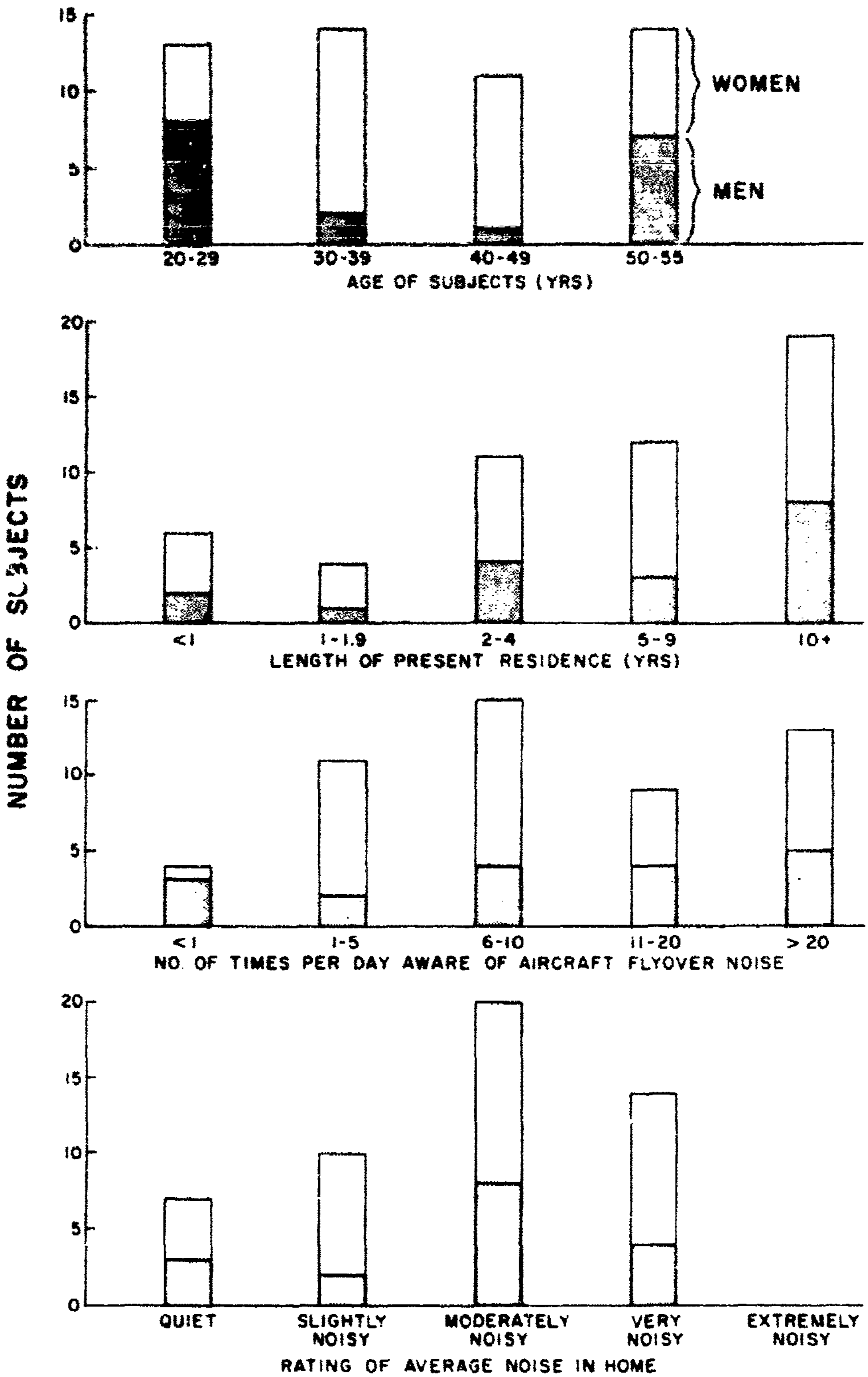


FIGURE 5. SUMMARY OF SUBJECT RESPONSE TO BACKGROUND INFORMATION QUESTIONNAIRE

time later you will hear the sound of an actual aircraft flyover followed by the same recorded flyover to which you assigned a number. Your job is to assign a number to the actual flyover according to how noisy it is compared to the recording. Mark this number on your answer sheet at the space provided for each aircraft flyover. For example, if you felt the actual flyover was twice as noisy as the recorded flyover, you would place a 200 in the space provided. If on the other hand you felt the flyover was one-half as noisy as the recording, you would place a 50 in the space. For your judgment, consider the aircraft flyover would occur 20-30 times during the day and night.

Repeat this procedure for each aircraft flyover.

The subjects were then presented with a recording of the noise from an aircraft flyover.* This reference flyover was then repeated, at the same level, immediately following each of the actual aircraft flyovers. In essence, then, the subjects were asked to develop a ratio scale of noisiness about a fixed reference having an assigned number of 100.

Test 1 involves the hypothesis that:

a) Subjects will equate, in terms of the same perceived noise level value, the noisiness of real flyovers with the noise from a realistic tape playback of a flyover;

---

* Two recordings were used in the tests. In the judgments of takeoff noise, a recording of the noise produced by a jet transport takeoff was used. For judgments of approach noise, a recording of a jet approach flyover was used. The recordings were originally recorded in the living rooms of the two test sites several days prior to the start of the judgment tests.

b) Subjects will produce a scale of subjective noisiness ratings that is essentially linear with the perceived noisiness (expressed in noys) calculated for the flyover stimuli. (Alternatively, we would expect the subjective ratings plotted on a log scale to be linear with the perceived noise level expressed in PNdB.)

Test 2, which was conducted both indoors (bedroom) and outdoors, was quite similar to Test 1. Subjects first listened to an actual flyover and were requested to assign the number of 100 to this flyover. They were then asked to judge all succeeding flyovers in the test series with respect to this reference flyover. Thus, in contrast to Test 1, subjects heard the reference flyover only at the start of the test period. And of course, in contrast to Test 1, Test 2 used noise from an actual flyover as a reference instead of a recorded noise signal.

Thus, Test 2 also involved hypothesis (b) of Test 1. In addition, it involved the hypothesis that increasing the time delay between the remembered reference and stimulus to be judged may increase the variance of judgment, but will not produce a systematic bias or shift in judged noisiness.

In Test 3, the remaining test, subjects were asked to rate the noise of the aircraft flyover on a scale having four descriptors (categories) as shown below:

Of No Concern	Acceptable	Barely Acceptable	Unacceptable

The four categories of acceptability (of no concern, acceptable, barely acceptable and unacceptable) were placed at equal intervals between the unlabeled end points.

Test 3 judgments were made indoors (in the bedrooms) and outdoors with subjects asked to judge the noise of actual flyovers. Test 3 was also conducted in the living room with recorded flyover noise signals. Here, the subjects were asked to judge the acceptability of a series of six recorded flyovers. In this test sequence, the same recording of flyover noise used as a reference in Test 1 was played back six times, with volume varied in 5 dB steps over a 25 dB dynamic range. The order of presenting the different flyover levels was randomized.

This test involves the hypotheses that:

a) Subjects drawn from a population of urban area residents and accustomed to hearing aircraft noise share a common conception of the acceptability of aircraft noise intrusion into their home life;

b) Subjects will produce a scale of acceptability ratings which can be uniquely correlated with objectively determined values of perceived noise levels.

E. Test Presentation

Subjects were divided into six groups of two to four people each for the tests. Two groups were placed in the living room, two in the bedroom, and two out-of-doors as indicated in Fig. 6. Thus, in the bedroom and outdoors, one group would be making Test 2 judgments and the other group, Test 3 judgments. In the living room, both groups were administered the same test at the same time, either Test 1 or Test 3. Both tests were given during the same session, one following the other. The order of presentation of the two tests was varied from session to session.

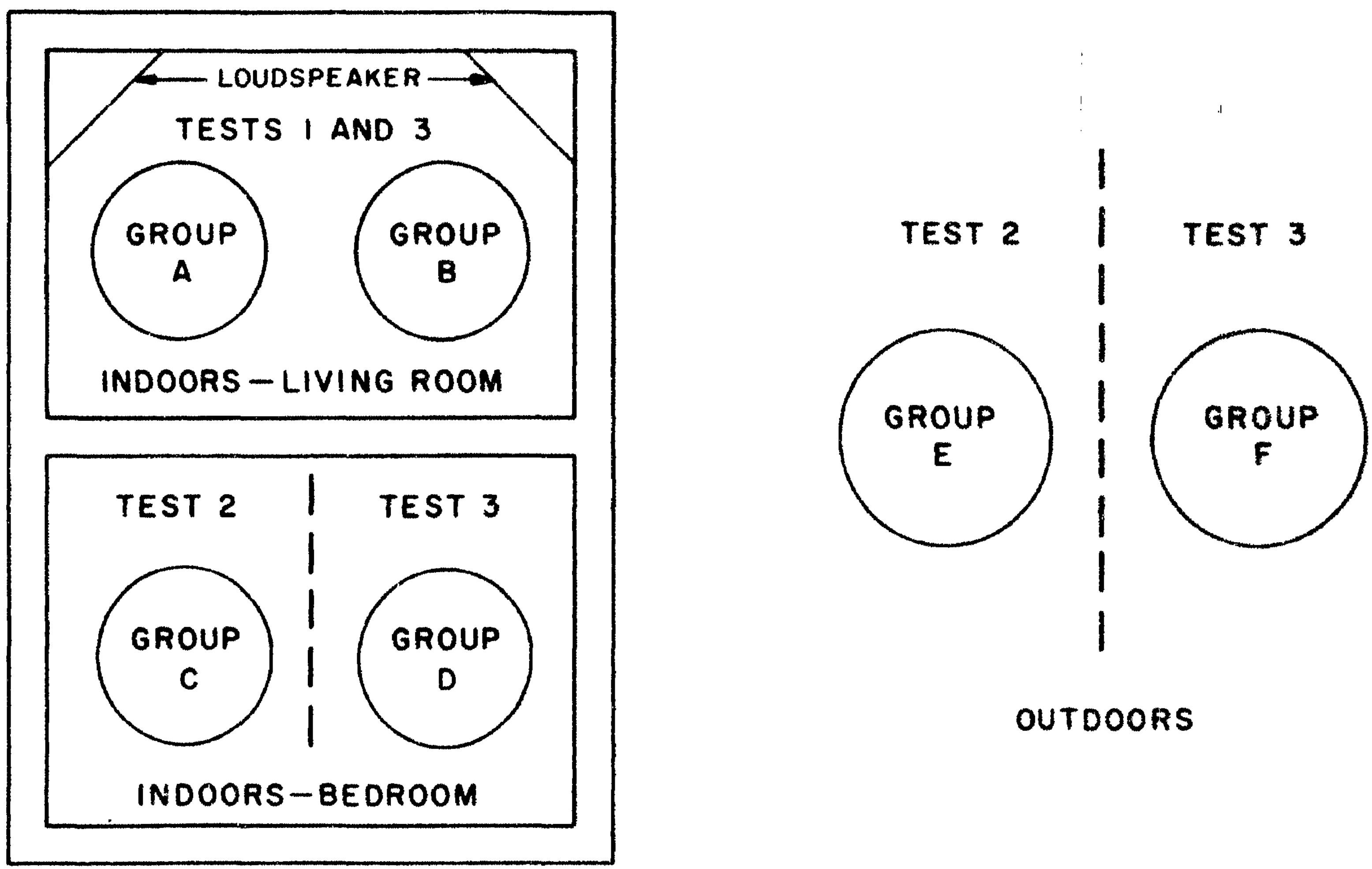


FIGURE 6. TEST ARRANGEMENT FOR AIRCRAFT NOISE JUDGEMENT TESTS

Each day of testing consisted of three test sessions. In each test session, subjects listened to noise from eight to twelve actual flyovers. Each test session typically lasted for 45 minutes. However, the session duration was quite variable, because of the unequal and somewhat unpredictable spacing between the arrivals or departures of aircraft from the airport.

Groups were rotated from one test location (living room, bedroom or outdoors) and type of test (Tests 1, 2 or 3) between sessions. Test session sequences for the different groups were ordered on a Latin square arrangement so that upon completion of the entire test series, each subject had been exposed to the same number of tests in each location, but in varying order. A typical schedule for the groups is given in Appendix B.

As noted in the general instructions given to each subject (reprinted in Appendix B) subjects were permitted to smoke, study, read, write and converse during the tests. A number of the women sewed or knitted during test sessions. Following the first few sessions with each new group of subjects, a number of conversational groupings would develop. Quite animated and vigorous discussions on diverse topics occurred in some test sessions. Thus, by the middle of each test series, the sessions resembled informal social gatherings in atmosphere and background noise level.

Thirty-five subjects (Test Series I and II) judged noise during two days (6 sessions) of exposure to approach noise and two days (6 sessions) of exposure to takeoff noise. Fifteen additional subjects (Test Series III) judge only approach noise during two days (6 sessions).

Scheduling of test sessions was determined largely by the relative frequency of arrivals and departures of aircraft at Los Angeles International Airport. Study of airline schedules showed that, for commercial jet transport aircraft, arrivals were a maximum from midmorning to noon and during supper and early evening hours. Departures showed a maximum in early morning and again at noon, with a secondary maximum also occurring in late afternoon.

Initial test sessions for both approach and takeoff judgments were conducted during midmorning and noon hours. Subjects for these sessions, Test Series I and II, were largely women. In order to obtain more male subjects, Test Series III sessions, during which subjects were exposed to approach noise, were held during early evening hours. A suitable evening period for listening to takeoff noise, which would provide a reasonable frequency of takeoffs, could not be arranged. For this reason, therefore, Series III subjects judged only approach noise.

III. ABSOLUTE JUDGMENTS OF ACCEPTABILITY

A. Separate Test Results

In analyzing Test 3 results, the judgments were scored by assigning numbers ranging from 0 to 10 to the divisions of the acceptability rating scale. This arbitrary numbering of the acceptability rating scale, done for convenience in scoring, does not imply that the intervals between the division should necessarily be of the same length. (That is, the interval between "of no concern", assigned the number 2 in scoring, and "acceptable" assigned the number 4, does not necessarily represent the same interval, as measured in PNdB, as that between the rating of "barely acceptable" and "unacceptable", assigned the numbers 6 and 8 in scoring.)

Results of the test are presented in Figs. 7 through 11. In these figures, the median scores (middle score, or fiftieth percentile) are plotted versus the observed flyover noise level. The median value was chosen rather than the average or mode because of the unknown spacing between divisions on the acceptability rating scale, and the possibility of nonnormal distributions of acceptable rating scores.*

Figure 7 shows the median judgment scores for observers listening to aircraft takeoff noise; similarily, Fig. 8 shows median scores for judgments of aircraft approach noise. Three sets of judgments are shown in each figure, representing judgments of actual flyovers, indoors (bedroom) and outdoors, and indoor judgments of recorded flyover noise.

---

* Actually, for most of the test results, the mean (or average) values and median values did not vary significantly. Thus, the test results shown in the figures would not be materially different if the average values had been plotted.

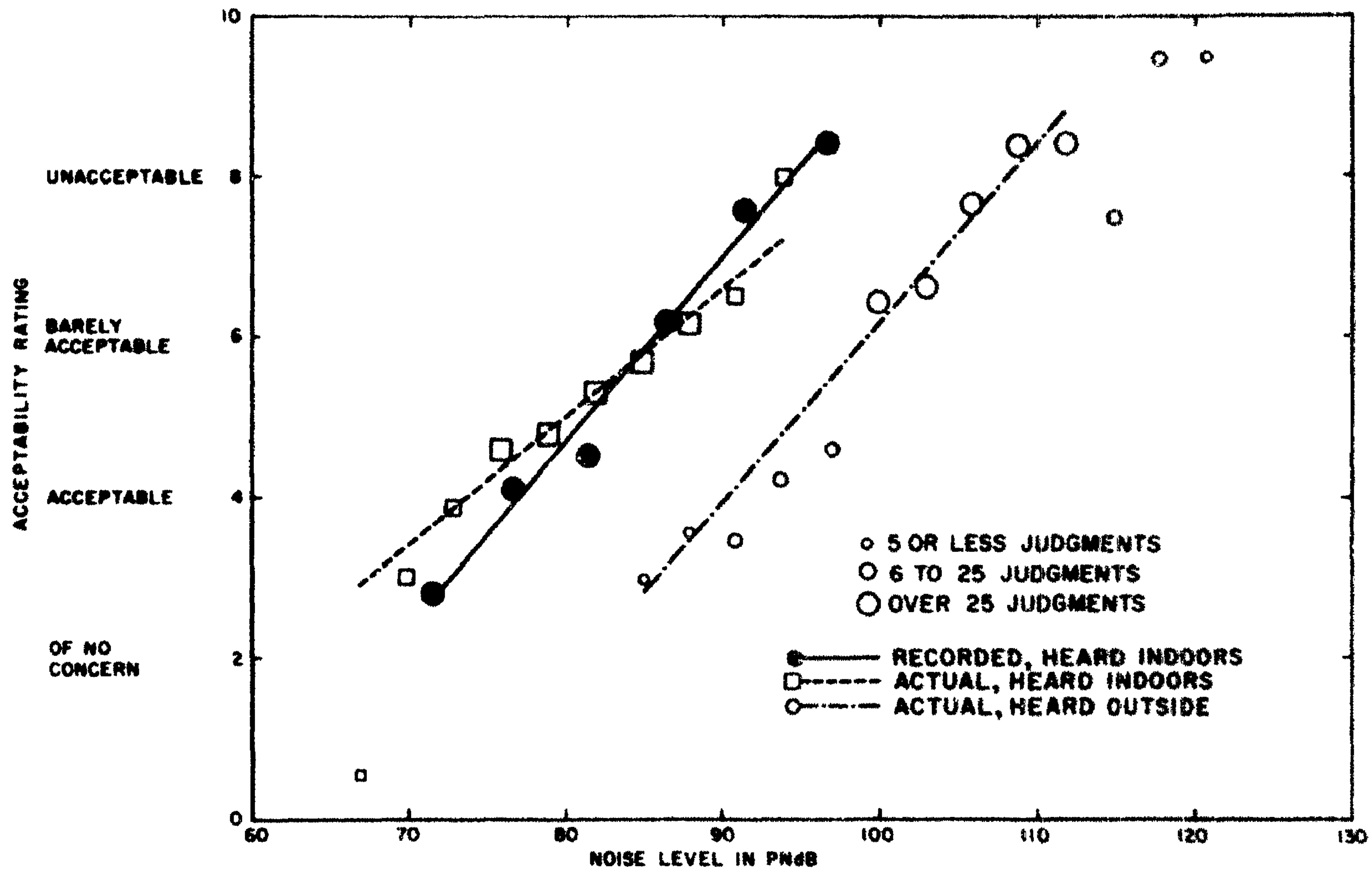


FIGURE 7. MEDIAN ACCEPTABILITY RATINGS — AIRCRAFT TAKEOFF NOISE (TEST 3)

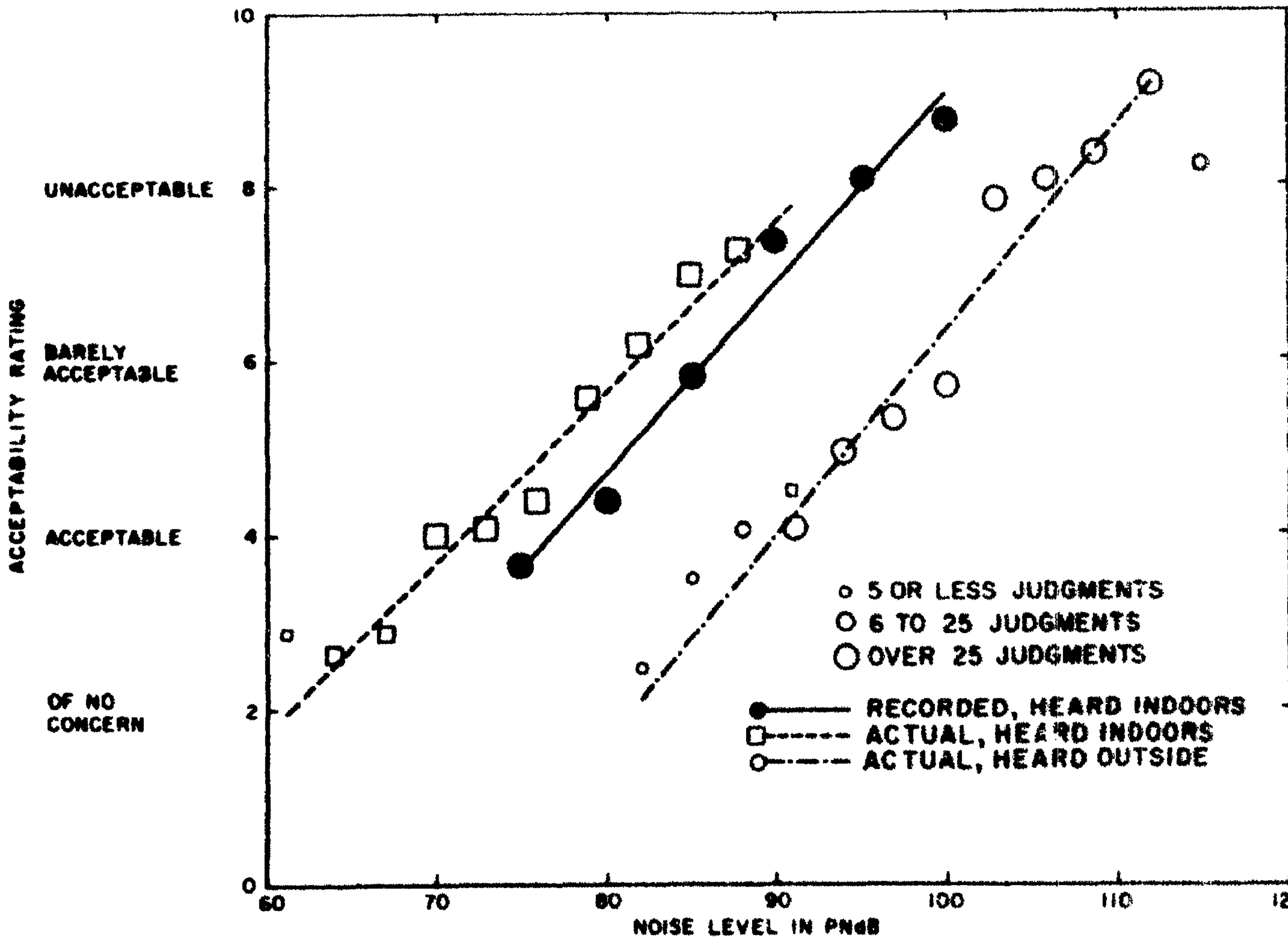


FIGURE 8. MEDIAN ACCEPTABILITY RATINGS – AIRCRAFT APPROACH NOISE (TEST 3)

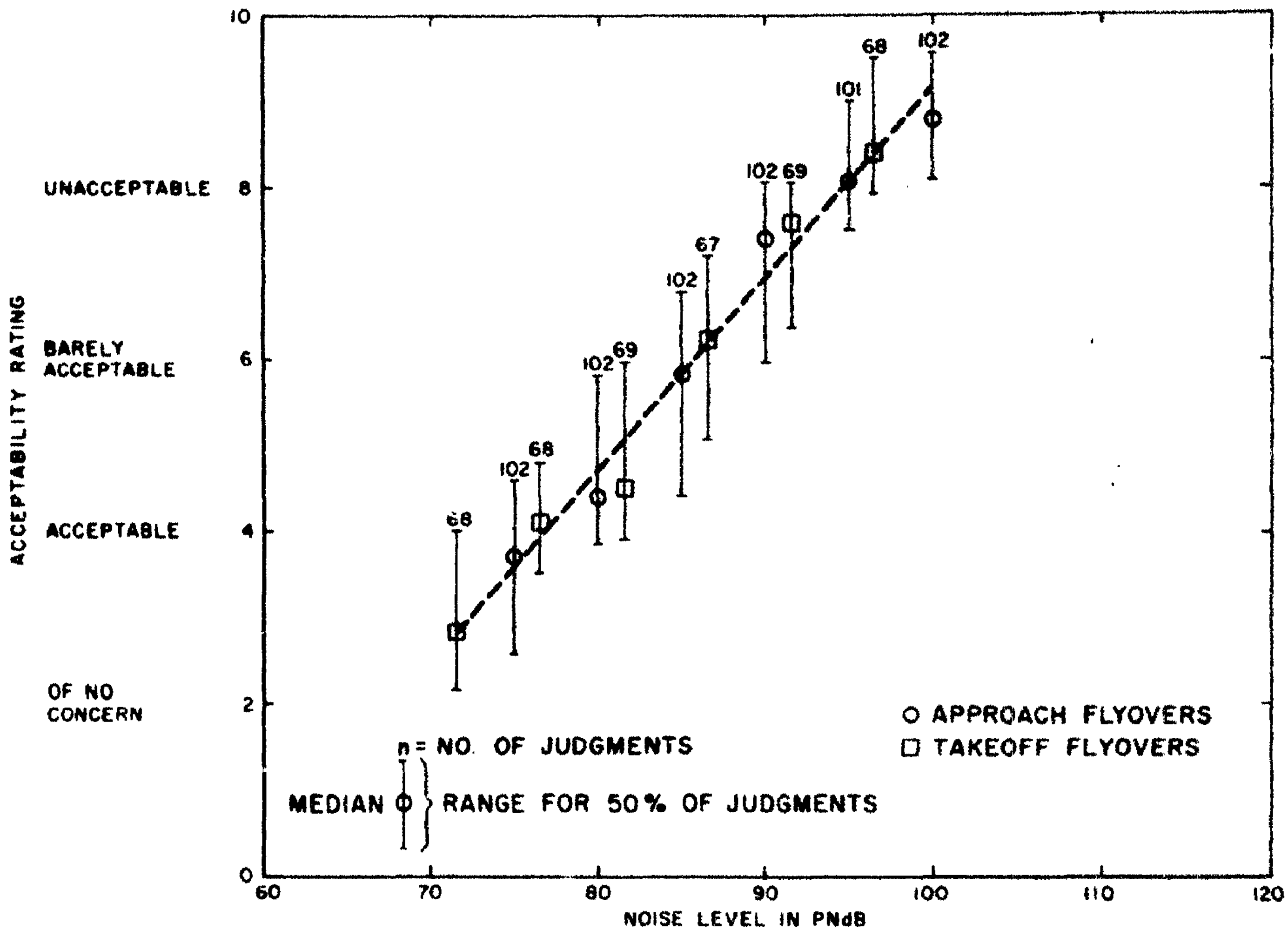


FIGURE 9. MEDIAN SCORES WITH INTERQUARTILE RANGES OF ACCEPTABILITY RATINGS — RECORDED TAKEOFF AND APPROACH FLYOVERS, HEARD INDOORS

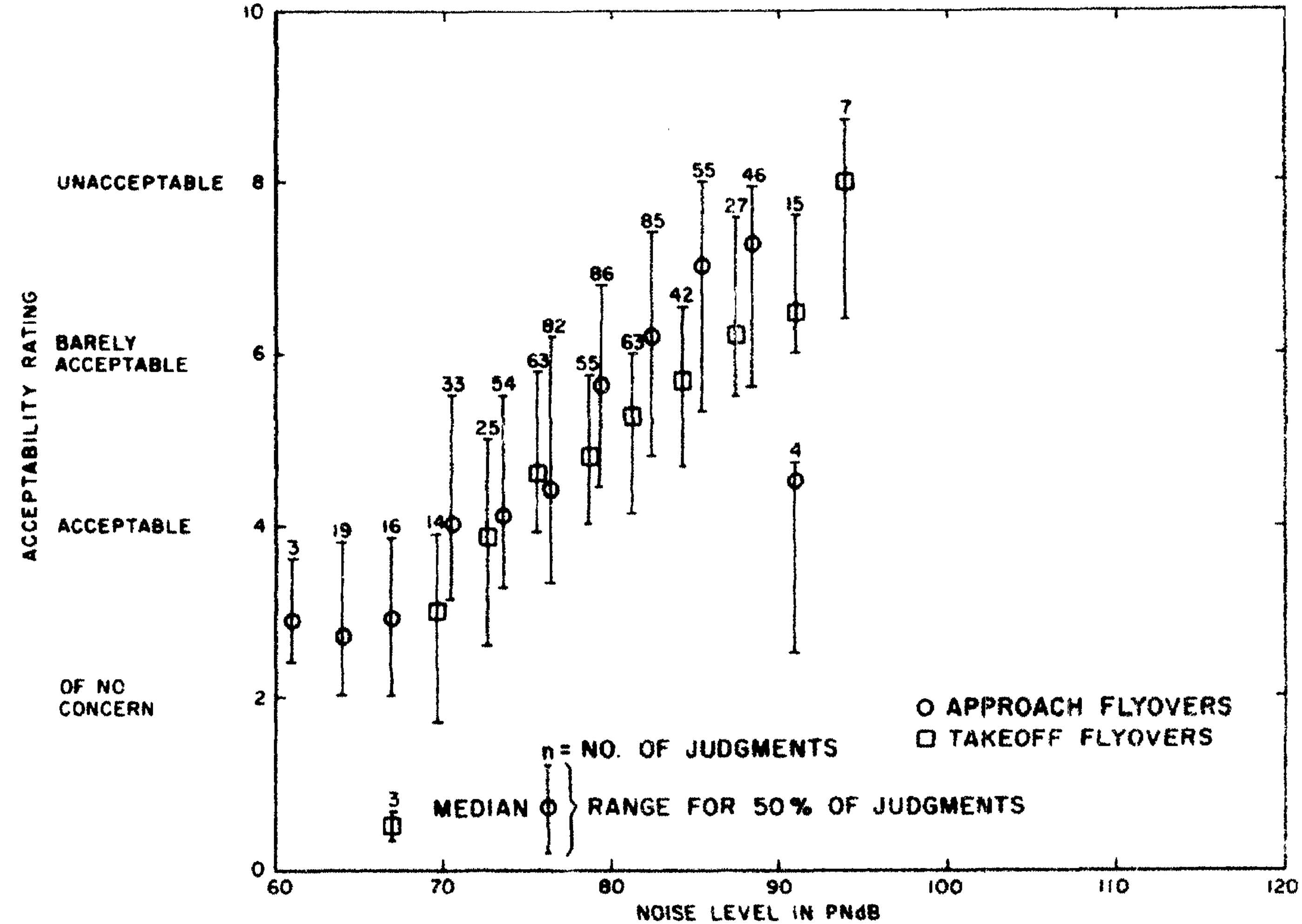


FIGURE 10. MEDIAN SCORES WITH INTERQUARTILE RANGES OF ACCEPTABILITY RATINGS – ACTUAL TAKEOFF AND APPROACH FLYOVERS, HEARD INDOORS

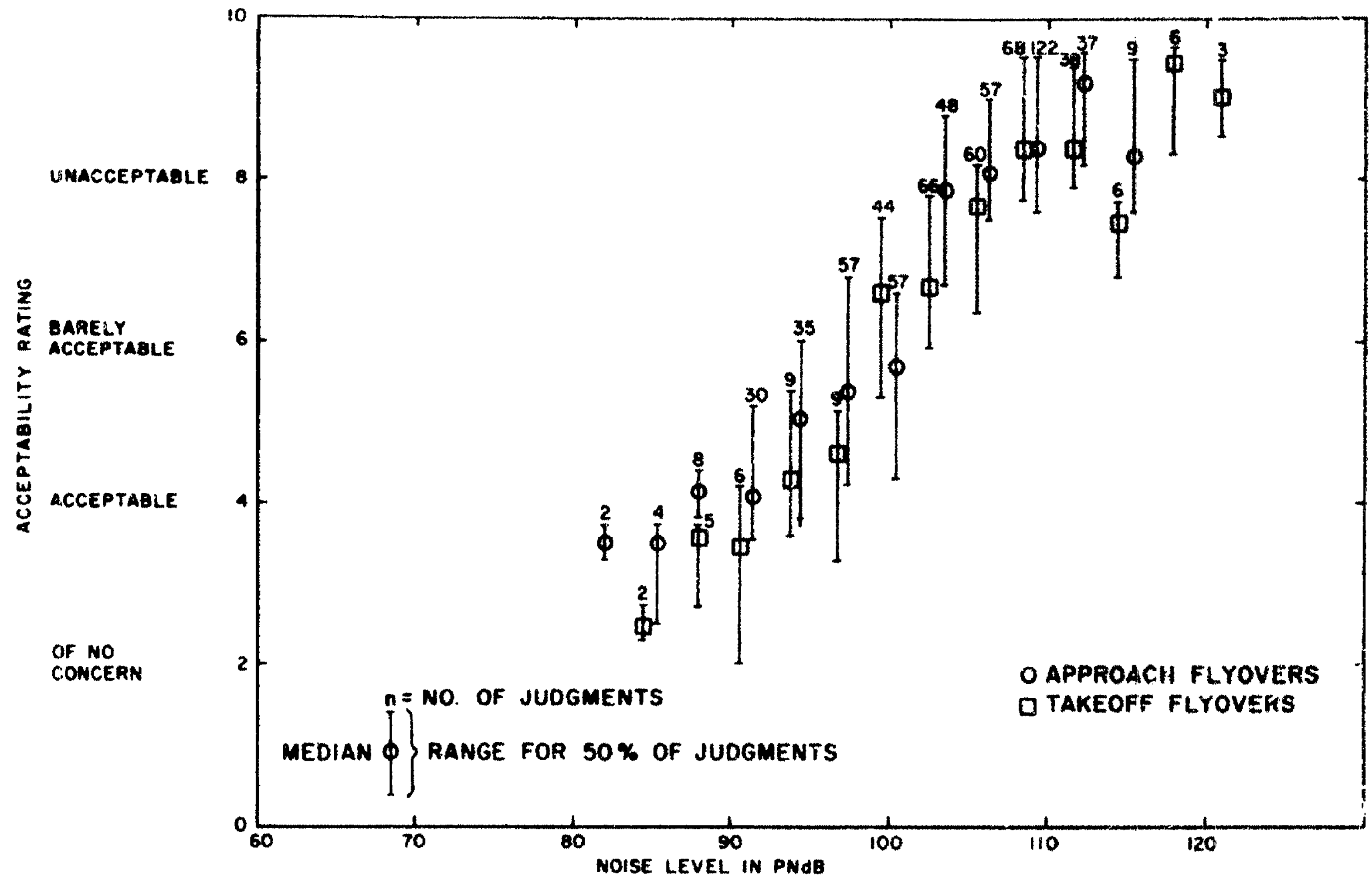


FIGURE 11. MEDIAN SCORES WITH INTERQUARTILE RANGES OF ACCEPTABILITY RATINGS — ACTUAL TAKEOFF AND APPROACH FLYOVERS, HEARD OUTDOORS

In Figs. 7 and 8, and in many of the following figures, three sizes of symbols have been used to provide an idea of the relative number of judgments involved at different intervals along the scale. The smallest size symobl indicates 5 or less judgments; the medium size, 6 to 24 judgments, and the large size, 25 or more judgments.

To facilitate interpretation and comparison of the different tests, we have fitted straight lines to the median scores.* The straight lines provide a relatively good fit to the data. However, if the individual test noise levels had extended over a much larger dynamic range, more complex mathematical curves would have been needed to provide a good fit to the data.

For example, with a greatly extended dynamic range in which the flyover noise levels extended to very high and very low levels, one might expect a sigmoidal, "s" shaped curve, to provide a better fit, since no subjective rating can be more than 10 or less than 0. Actually, the judgment scores for the flyovers heard outdoors (see Figs. 7 or 8) do tend to show a decrease in slope for noise levels above about 110 PNdB. Because of this change in slope at the higher noise levels, the straight line fitted to the outdoor scores was arbitrarily based on the judgment values extending up to a maximum noise level of 112 PNdB.

---

* The straight lines shown in the figures were fitted to the median scores by standard linear regression procedures.11/ Weightings were assigned to the median scores equal to the number of judgments used in determining the median scores. Later, in making formal statistical tests of the significance of differences between slopes or intercepts of the straight lines, the linear regression lines were re-calculated using all of the data points. This recalculation eliminated the simplifying assumption that data points in a given PNdB interval could be concentrated at the median score for that interval. There was little difference in the linear regression curves calculated by the approximate procedure (based on median scores) and the detailed procedure.

Figures 9, 10 and 11 compare judgment scores for approach noise and takeoff noise. Figure 9 shows judgment scores for recorded noise signals heard indoor at the two test sites. Figure 10 shows the two sets of indoor judgments of actual flyovers; Fig. 11 shows the judgments for the actual flyovers heard outdoors. In these graphs, median scores and the upper and lower quartile limits are shown. The number shown above each bar is the total number of judgments observed at that noise level for the particular test. In Fig. 9 a regression line is also shown, representing the mean of the separate weighted regression lines for the approach and the takeoff judgments. Regression lines have been omitted from Figs. 10 and 11 for clarity.

A trend towards a change in slope of the mean curves relating judgments to perceived noise levels at high and at low noise levels is evident in Fig. 10 and 11, although substantiated by relatively few judgments. Also apparent is a somewhat increased spread of data for the judgments of actual noise compared to the recorded noise signals. Part of this apparent increase in scatter results from the greater range in noise levels encountered in the "live" tests, and also from the small number of judgments occurring at either end of the dynamic range encompassed by the actual flyover noise judgments.

Several factors are evident from Figs. 7 through 11:

a) For indoor noise judgments of either approach or takeoff noise, differences between judgments of actual flyovers or recorded flyovers are not large. Tests show, however, that some of the differences are statistically significant. In Fig. 7, the difference in slope between the regression lines fitted to the two sets of indoor data, (recorded and actual) is significant

at the 1% level.* And in Fig. 8 the difference in displacement between the two regression lines for indoor judgments is also significant at the 1% level. One may also note that the slopes of the two regression lines correlating the ratings of the actual flyovers judged indoors are slightly less than the slopes of the other regression lines.

b) Considering noise heard indoors or heard outdoors, there is little significant difference in the median judgments of approach noise or of takeoff noise.** Thus, although Fig. 4 showed that there were generally sizeable differences in the time duration of the approach noise and takeoff noise signals, the median judgments of approach and takeoff noise show no significant difference when plotted versus the maximum perceived noise level. This is contrary to what might be expected on the basis of recent relative judgment tests which indicate that a difference in time duration should

---

* By the t test, Reference 10.

The level of significance indicates the percent risk of error in accepting the test findings (i.e., a difference in curve intercepts or slopes) as real for the subjects tested. If there really were no actual differences in subject responses, one would expect, in repeating the judgment tests many, many times, to find an experimental test difference this large only 1% of the time.

** Statistical checks show that the differences in slopes of the regression curves for indoor judgments of actual approach and takeoff flyover noise is not significant at the 5% level; however the difference in intercepts of the two curves is significant at the 1% level. Differences between pairs of outdoor judgment curves and indoor judgment curves for recorded flyovers are not significant at the 5% level.

cause a shift in judgments.3/ A possible compensating factor in these tests was the probability that many of the approach flyover noise signals contained stronger pure tone components than the takeoff noise signals. The increased pure tone content of the approach noise flyovers may have tended to increase the noisiness of the flyovers offsetting the decreased noisiness due to the shorter time duration of the approach flyovers.3,12/ This possibility was not investigated since no detailed analysis of pure tone content in the noise signals was made.

c) For either approach or takeoff noise judgments, there is a sizeable and statistically significant displacement between indoor judgments and outdoor judgments for a flyover of the same perceived noise level. This displacement indicates that for flyover noise of the same perceived noise level, most observers will assign a less acceptable rating to the noise when heard indoors than when heard outdoors.

The displacement between indoor and outdoor judgments of aircraft noise was earlier observed in judgment tests conducted at the 1961 Farnborough Air Show in Great Britain.7/ In these tests, subjects rated aircraft flyover noise heard indoors and outdoors on a category scale of intrusiveness. (Actual categories on the scale were: not noticeable, noticeable, intrusive, annoying, very annoying, and unbearable.) The displacement at the midpoint of the objective rating scale was found to be about 18 dBA. This value can be compared with an average value of approximately 14 PNdB observed in the present tests. And in both the present and the British tests, the shift between indoor and outdoor judgments is somewhat less than the magnitude of noise reduction provided by the test building structures. For example, the mean noise reduction for

the different test rooms, ranging from about 21 to 24 PNdB, was 7 to 10 PNdB greater than the mean observed displacement in judgments.

B. Composite Test Results

Two composite curves relating perceived noise levels with acceptability ratings are shown in Fig. 12. One curve represents the mean of the four regression lines for indoor judgment tests (recorded and actual flyovers, approach and takeoff noise); the other curve is the mean of the two regression lines calculated from the outdoor judgments (actual flyovers, approach and takeoff noise).

In Fig. 12 both curves are plotted versus the perceived noise level measured outdoors. To accomplish this, perceived noise levels corresponding to indoor category judgments have all been increased by 20 PNdB, 20 PNdB being taken as a representative building noise reduction value. Hence, the indoor judgment curve of Fig. 12 represents judgments of aircraft noise heard indoors but measured outdoors. The two curves are nearly parallel but are displaced from one another by an amount of about 5 PNdB at an acceptability rating of 4, "acceptable", and about 8 PNdB at an acceptability rating of 8, "unacceptable".

Figure 12, representing composite test results, can be used to indicate approximately the mean judgments of the people tested. For example, Fig. 12 indicates that for a flyover creating a maximum noise level of 110 PNdB measured outdoors, the average judgment of outdoor listeners would be "unacceptable" or worse; for indoor listeners exposed to the same flyover, (and located inside a building providing a 20 PNdB reduction in noise levels), their average judgment would lie midway between "barely acceptable" and "unacceptable". Alternatively, we can say that to have a mean rating of "acceptable" or better, the noise level should not exceed 90 PNdB for outdoor listeners or 95 PNdB (as measured outdoors) for indoor listeners. Likewise, for a mean rating of "barely acceptable" or better, the noise level should not exceed

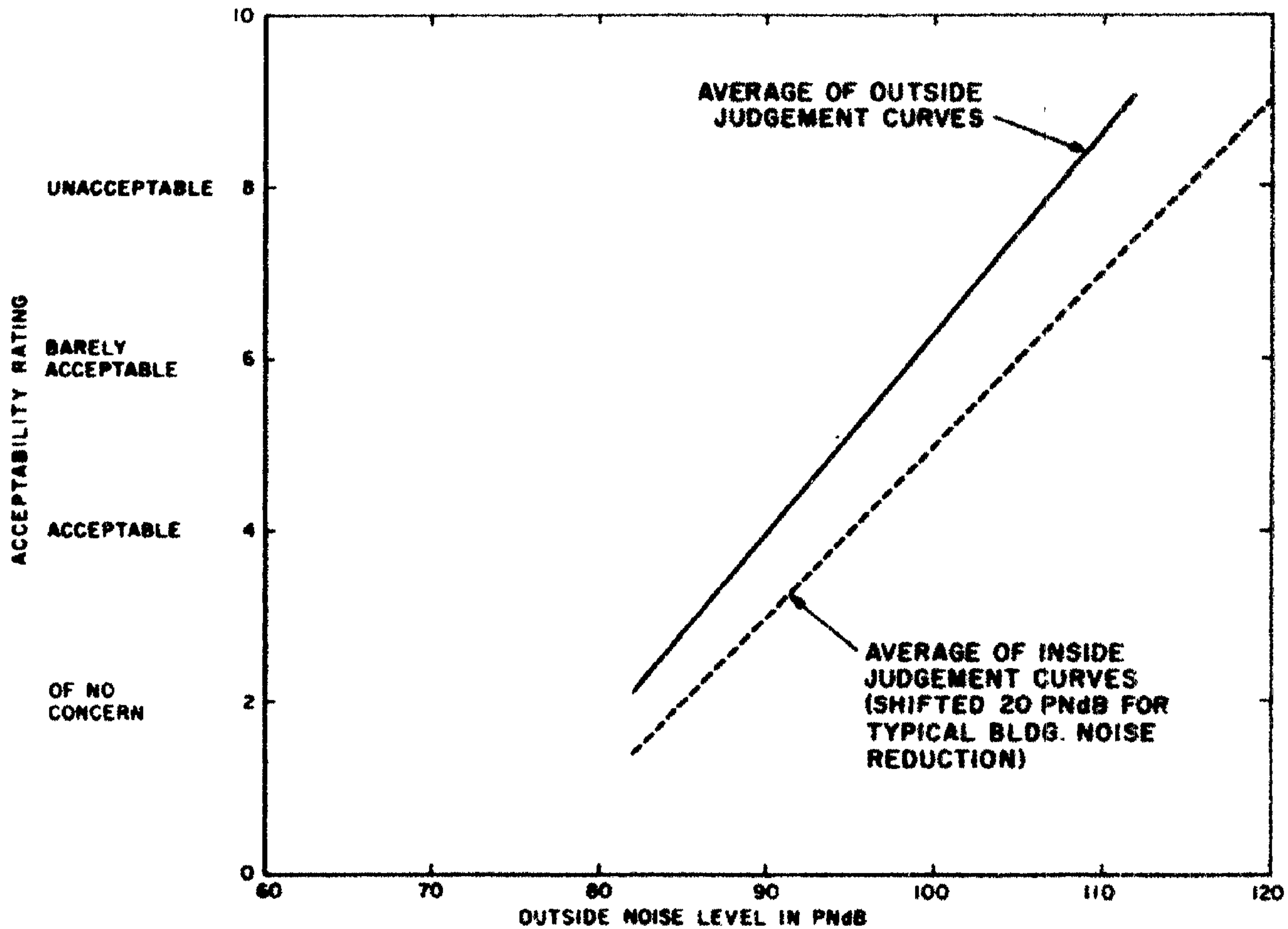


FIGURE 12. COMPARISON OF AVERAGE OUTDOOR AND INDOOR ACCEPTABILITY JUDGEMENT CURVES — COMBINED TAKEOFF AND APPROACH NOISE JUDGEMENTS

99 PNdB for outdoor listeners or 105 PNdB (as measured outdoors) for indoor judgments.

The composite test results are compared with the subjective rating scales of the Farnborough outdoor judgment tests in Fig. 13. In this figure the acceptability ratings for indoor and outdoor judgments, taken from Fig. 12, are plotted alongside the "intrusiveness" and the "noisiness" ratings from the Farnborough tests.* In the Farnborough test analysis, quadratic curves were used for correlation between judgments and noise levels; hence, there is unequal spacing between the different categories in the British scales.

From Fig. 13, it will be noted that the acceptability rating scale is quite compressed in comparison with the British rating scales. Test signals did not extend over as large a dynamic range and particularly to as high noise levels as the British tests. On this basis it may be argued that if a greater dynamic range had been used, the acceptability rating scale would have been spread out over a larger range of noise levels. This is in line with a tendency for subjects to automatically cover the category scale regardless of the actual dynamic range used in the test. This point remains to be further explored in tests involving extended dynamic ranges of stimuli.

One other difference between the different judgment tests should be noted. In making the acceptability judgments, our subjects were specifically asked to judge flyover noise in the context that the flyovers would occur 20 to 30 times during the day and night.

---

* The data in Fig. 13 are taken from Reference 7. In drawing Fig. 13, the perceived noise level scale given in Reference 7 has been adjusted by an amount of 1 PNdB to reflect recent changes in the tables for calculating PNdB.3/

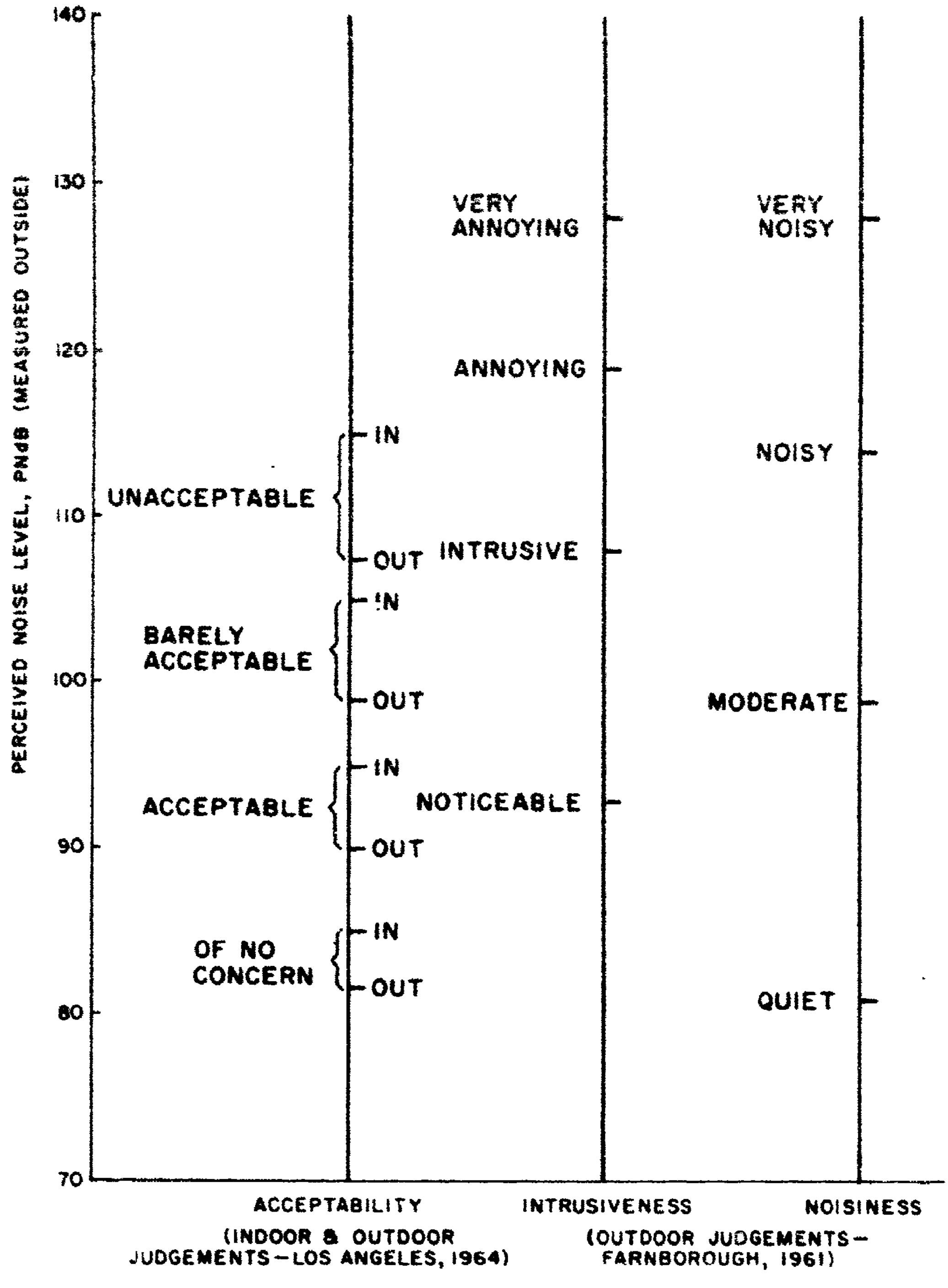


FIGURE 13. COMPARISON BETWEEN PERCEIVED NOISE LEVE OF AIRCRAFT FLYOVERS AND CATEGORY SCALES OF ACCEPTABILITY, INTRUSIVENES AND NOISINESS

In the British tests, subjects were not instructed to interpret the flyovers in terms of any particular number of occurrences. If the British subjects tended to judge the noisiness, or intrusiveness, in terms of single flyovers, and if our subjects truly did judge in the context of 20 to 30 occurrences per day, one might expect to find the relation between the different category rating scales to be considerably different than that indicated in Fig. 13. On the basis of current estimates of the effects of number of occurrences on subjective judgments, the relationship between category scales could shift by an amount of 15 to 20 PNdB over that indicated in Fig. 13.* Such a sizeable displacement would then make the British categories of "very annoying" or "very noisy" approximately equivalent to "unacceptable" on the acceptability category scale.

---

* Results of British tests, in which subjective annoyance ratings were correlated with measurements of aircraft noise and volume of aircraft operations, indicated that the average annoyance was a function of the sum of the noise level (in PNdB) plus 15 log N, where N is the number of aircraft flyovers per day.13/ In procedures used in this country for predicting average community response to aircraft noise, it is assumed that adverse response varies with 10 log N.14/ See Part I of this report for an extended discussion of this point.

C. Dispersion of Data

Before drawing firm conclusions or comparisons from the data, some discussion of the dispersion of the data is needed. Figures 9, 10 and 11 have shown considerable scatter in the judgments, with judgments spreading over two or more categories for flyovers having the same maximum noise level.

The root-mean-square (rms) value of the standard deviations of judgments at specific noise levels may be used as an indication of test variability.* These values ranged from 1.35 to 1.59 units on the acceptability scale for the different tests; the rms standard deviation for all tests combined was 1.46 units. If one assumes an average slope of 0.20 for the curve relating the acceptability ratings to perceived noise levels, then the rms standard deviations ranged from 6.7 to 8.0 PNdB for the different tests with a rms standard deviation for all tests of 7.3 PNdB.

Another measure of the scatter in data can be stated in terms of the fit of the regression lines to the data. For the regression lines, the standard error of estimate, ($s_{y/x}$) provides an indication of the scatter of the data points in the vertical direction about the regression line. This value ranged from 1.41 units (7.1 PNdB) to 1.81 (9.1 PNdB) units for the different regression lines. The rms value for all tests was 1.66 units (8.3 PNdB).

These standard error values are of help when interpreting the data presented in Figs. 7 through 12 in terms of the proportion of judgments which

---

* It was found that the standard deviation values for judgments at the different noise levels generally did not vary drastically over the dynamic range o among the different tests.

may fall above or below a certain acceptability category. For example, from Fig. 12 one can say that while 50% of subjects located outdoors may assign a rating of "barely acceptable" or better to a flyover with a noise level of 99 PNdB, 95% of the subjects are not likely to register a rating of "barely acceptable" or better, until the flyover noise level (for outdoor judgments) has been lowered to 82.4 PNdB (99 PNdB - 2 x 8.3 PNdB).

In view of the relatively large dispersion, it is particularly interesting to determine the major sources of error contributing to the observed dispersion. The probable four main sources of variability are listed in Table III, together with estimates of the probable size of the standard deviation attributable to each source. These estimates are based upon analysis of the test scores, as summarized in Appendix C.

The estimates of variability given in Table III are not of a high order of precision, but they do clearly indicate that the variability resulting from differences between subjects, individual subject inconsistency and correlation between objective and subjective scales are of the same order of magnitude.

The conclusion that the variability due to lack of correspondence between objective and subjective scales is probably less than the variability introduced by differences between subjects, or lack of consistency in individual subject judgments, seems reasonable when standard deviation values (for judgment scores at specific noise levels) for the different tests are compared.

RMS standard deviation values for the living room tests in which subjects listened to recorded flyovers which differed in noise level but not in time duration, time pattern or spectrum content, were not any smaller than the standard deviation values for judgment tests of actual flyovers. The noise signals produced by the actual flyovers differed greatly, of course, in time duration, time patterns and spectrum shape and content.

TABLE III

MAIN SOURCES OF VARIABILITY IN CATEGORY JUDGMENT TESTS OF AIRCRAFT NOISE ACCEPTABILITY

SOURCE OF VARIABILITY	ESTIMATED STANDARD DEVIATIONS	
	ACCEPTABILITY SCALE	PNdB
Lack of consistency or repeatability in subjects' judgments	1.0	5.0
Variability in judgments among subjects	0.9	4.5
Lack of correspondence between objective measure of noise (perceived noise level) and subjective measures of noise acceptability	0.85	4.3
Errors in noise measurement and variations in the noise environment at different subject test positions	0.4	2.0

Hence, one would expect that if the variability due to lack of agreement between subjective and objective rating scales was large, then the standard deviation for the living room listening tests would be measurably less than in the tests where actual flyovers were judged.

D. Effects of Age, Sex and Type of Aircraft

1) Age and Sex

Test 3 judgments of approach noise have been compared for several subgroups of listeners.

a) Men versus women

b) Two age groups, 20-29 years versus 50-55 years.

Only judgment tests of approach noise were compared because of the near-equal numbers of test subjects in each of the subgroups for the approach tests. Figures 14, 15 and 16 show the median judgment scores of men and of women for the recorded flyovers heard indoors (Fig. 14), and the actual flyovers heard indoors (Fig. 15) and heard outdoors (Fig. 16). Weighted regression lines have been fitted to the data with the weighting proportional to the number of judgments in each PNdB category. Only a single curve has been plotted in Fig. 16 because of the close agreement between the separate sets of data.

Figures 14 and 16 show very good agreement between the judgments of men and women, while Fig. 15 does indicate some difference in judgments. Note that in judgments of actual flyovers at moderate or low flyover noise levels, men tended to rate the flyover noise less acceptable than the women. This tendency is in agreement with the (slight) differences between sexes found in the Farnborough tests.

Figures 17, 18 and 19 show similar correlation curves for the judgments of approach noise for the 20-29 year age group and the 50-55 year age group. In Fig. 17 the

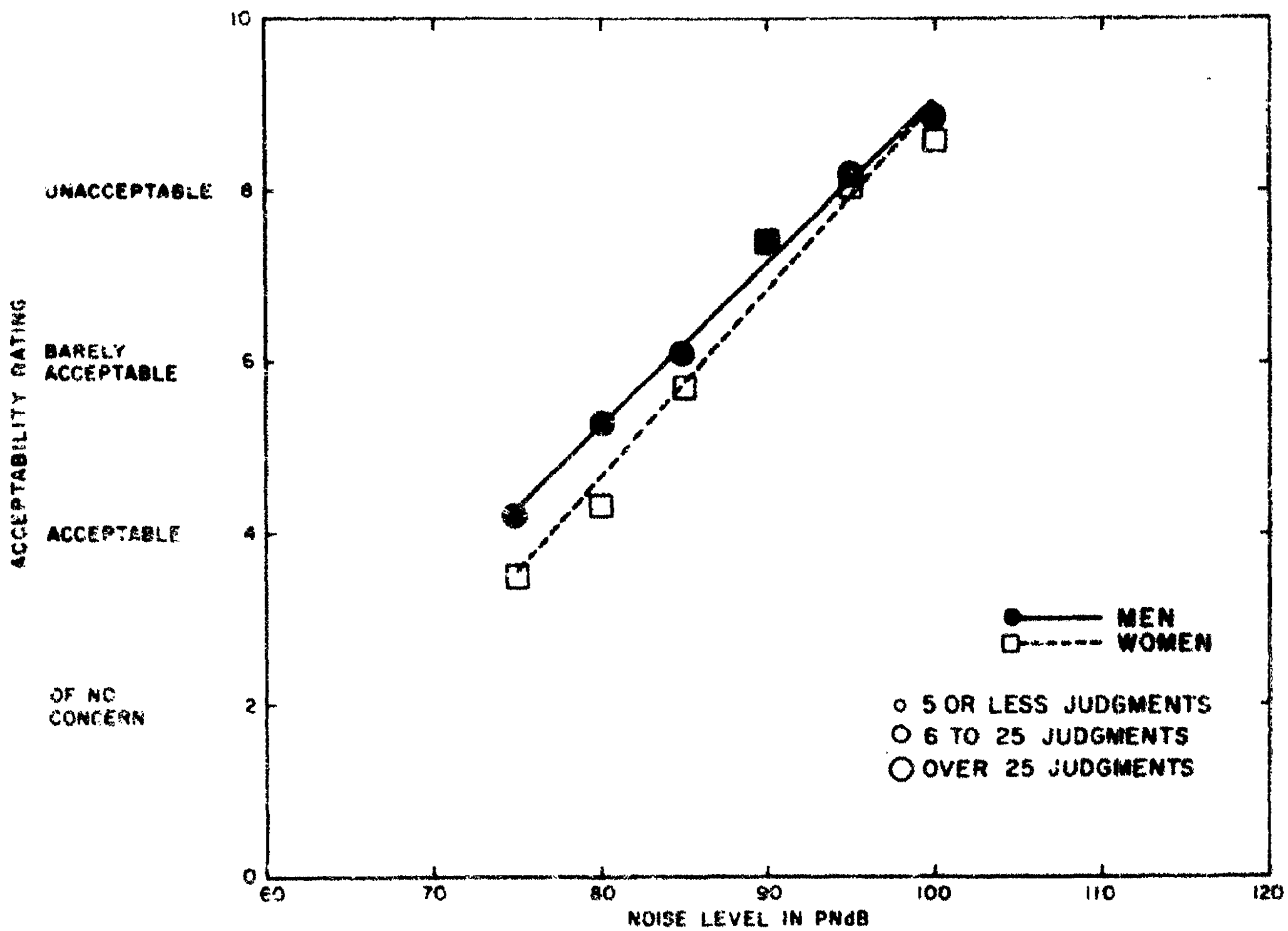


FIGURE 14. MEDIAN ACCEPTABILITY RATINGS – RECORDED APPROACH FLYOVERS HEARD INDOORS – MEN VS WOMEN

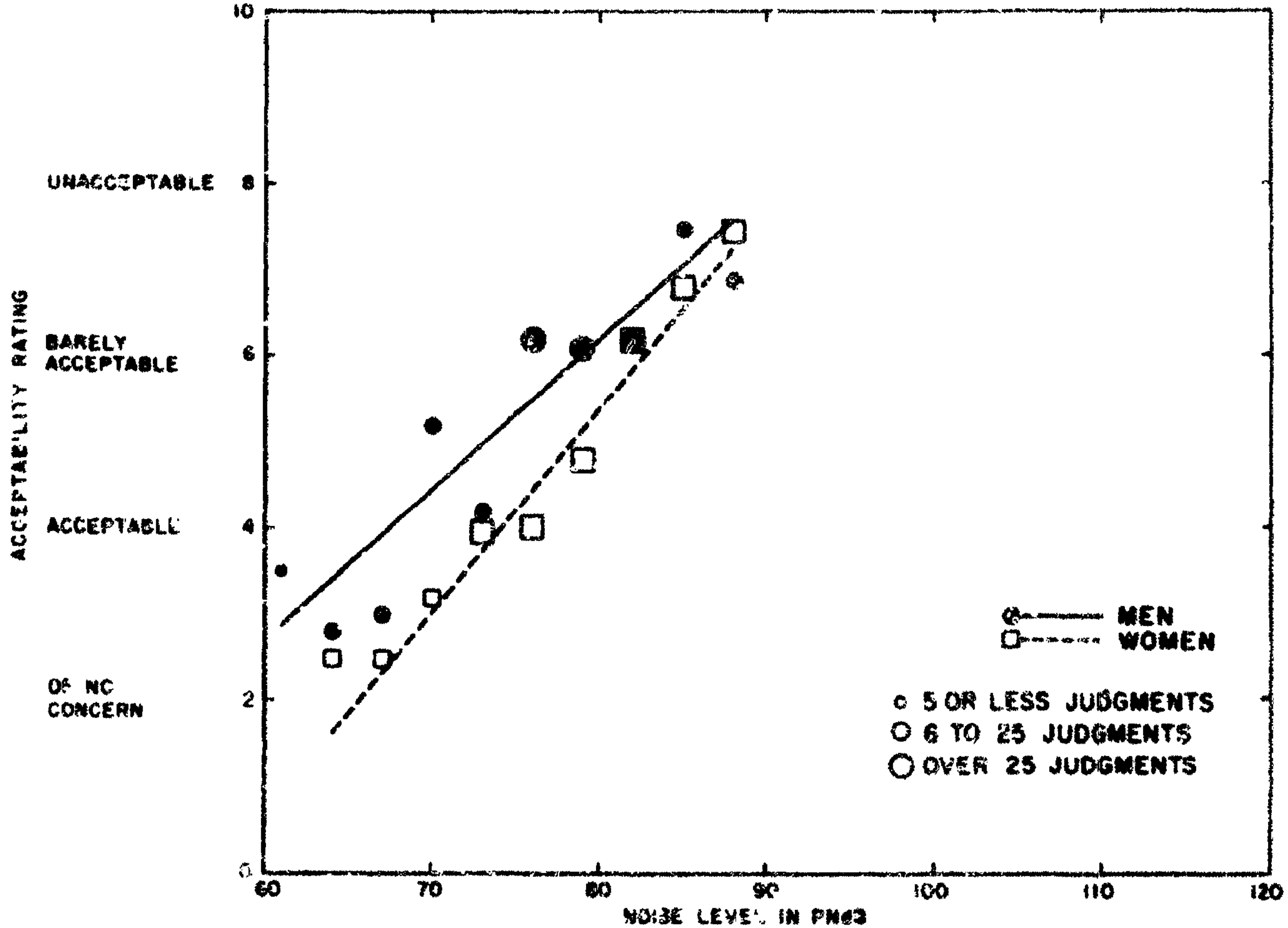


FIGURE 15. MEDIAN ACCEPTABILITY RATINGS – ACTUAL APPROACH FLYOVERS HEARD INDOORS – MEN VS WOMEN

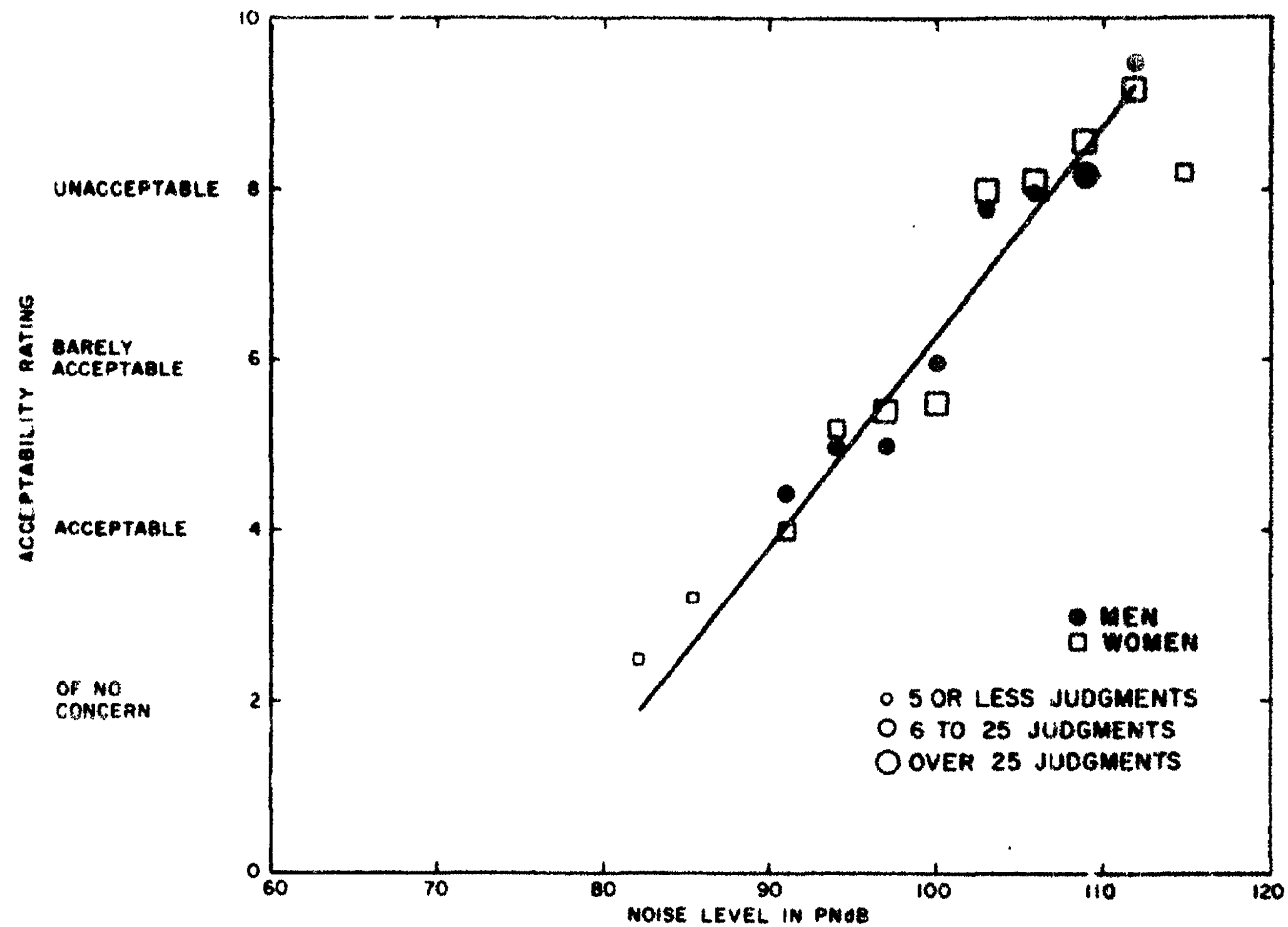


FIGURE 16. MEDIAN ACCEPTABILITY RATINGS - ACTUAL APPROACH FLYOVERS HEARD OUTSIDE — MEN VS WOMEN

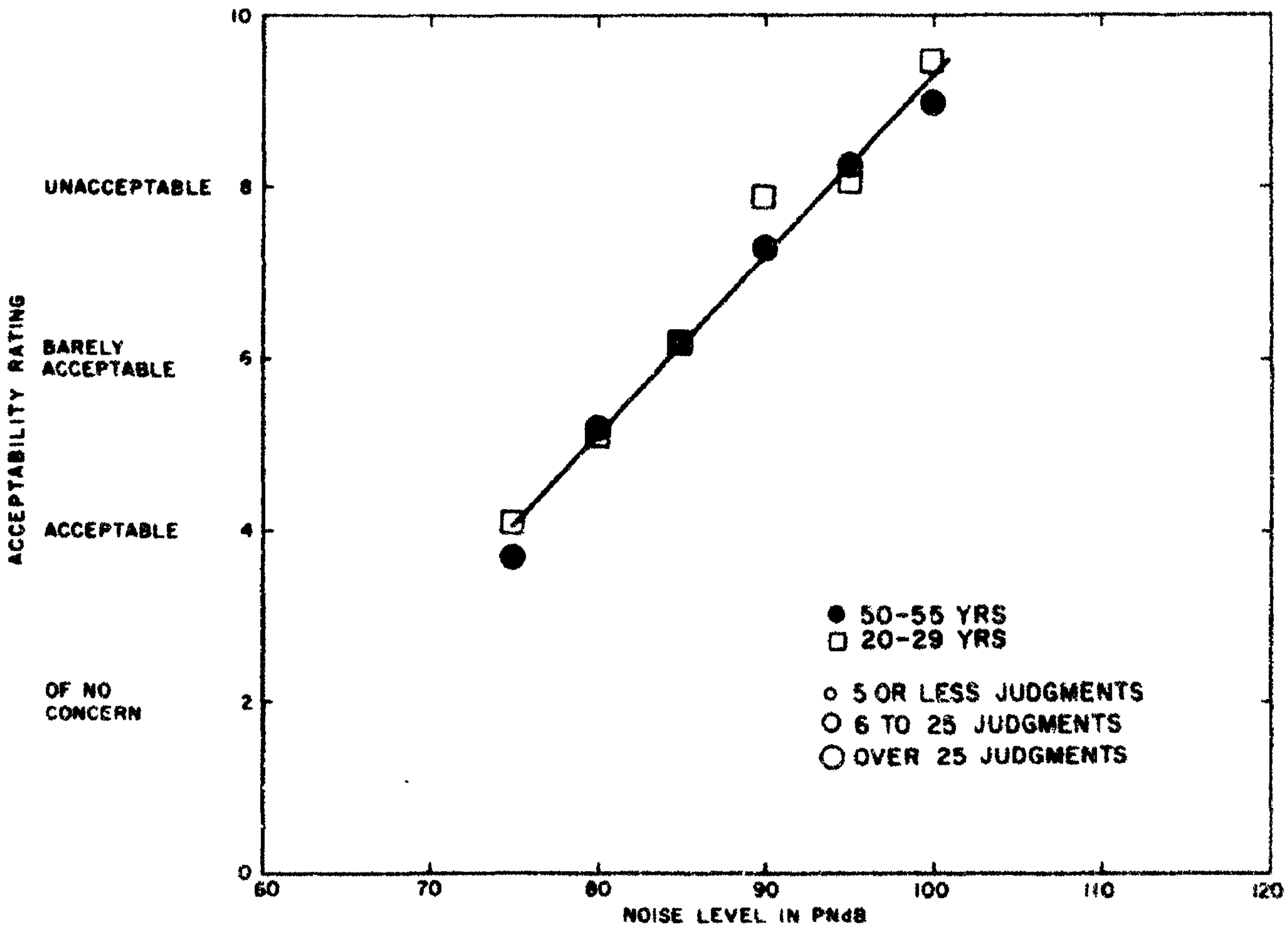


FIGURE 17. MEDIAN ACCEPTABILITY RATINGS - RECORDED APPROACH FLYOVERS HEARD INDOORS - 20-29 YRS VS 50-55 YRS

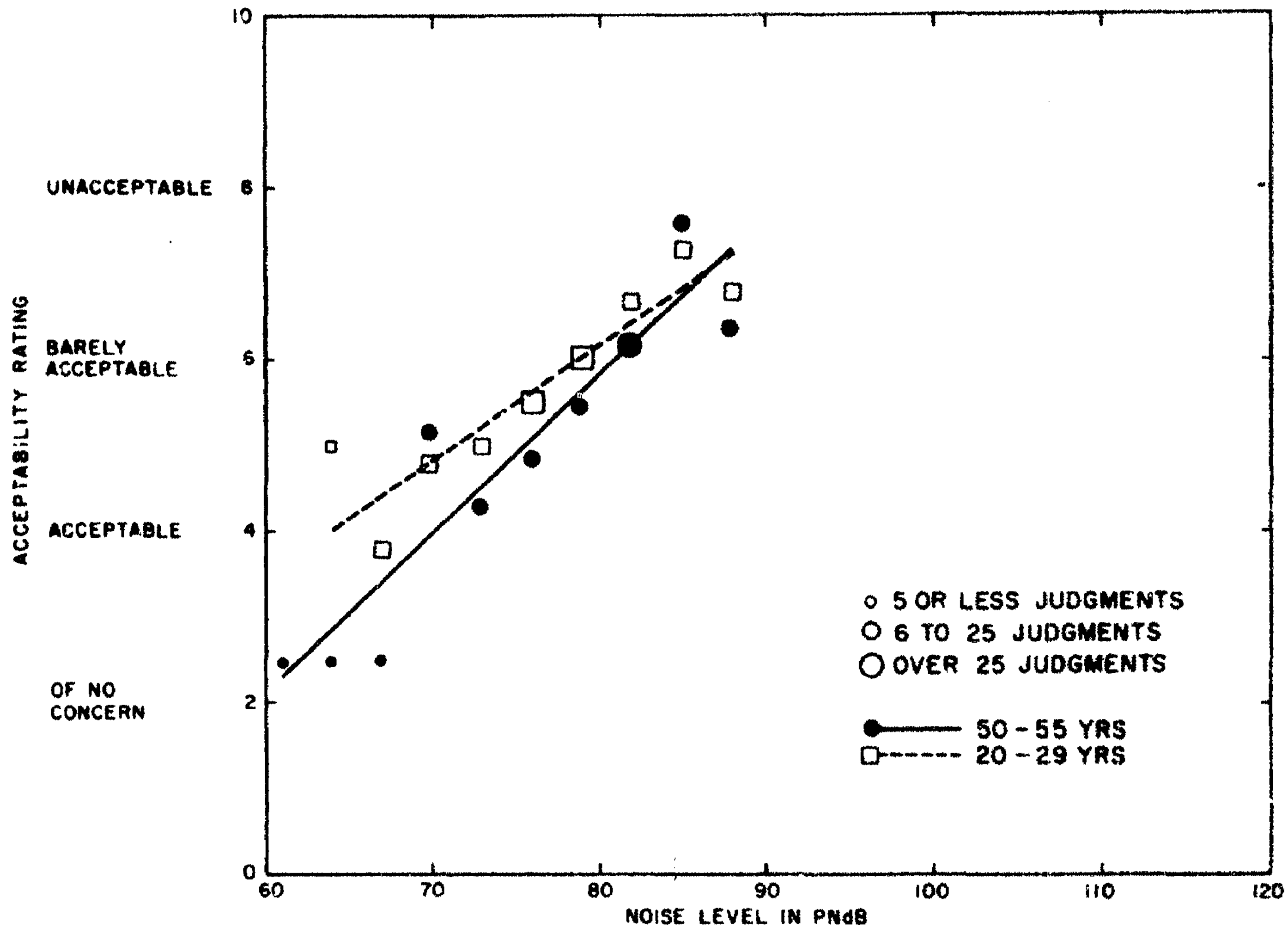


FIGURE 18. MEDIAN ACCEPTABILITY RATINGS - ACTUAL APPROACH FLYOVERS HEARD INDOORS - 20-29 YRS VS 50-55 YRS

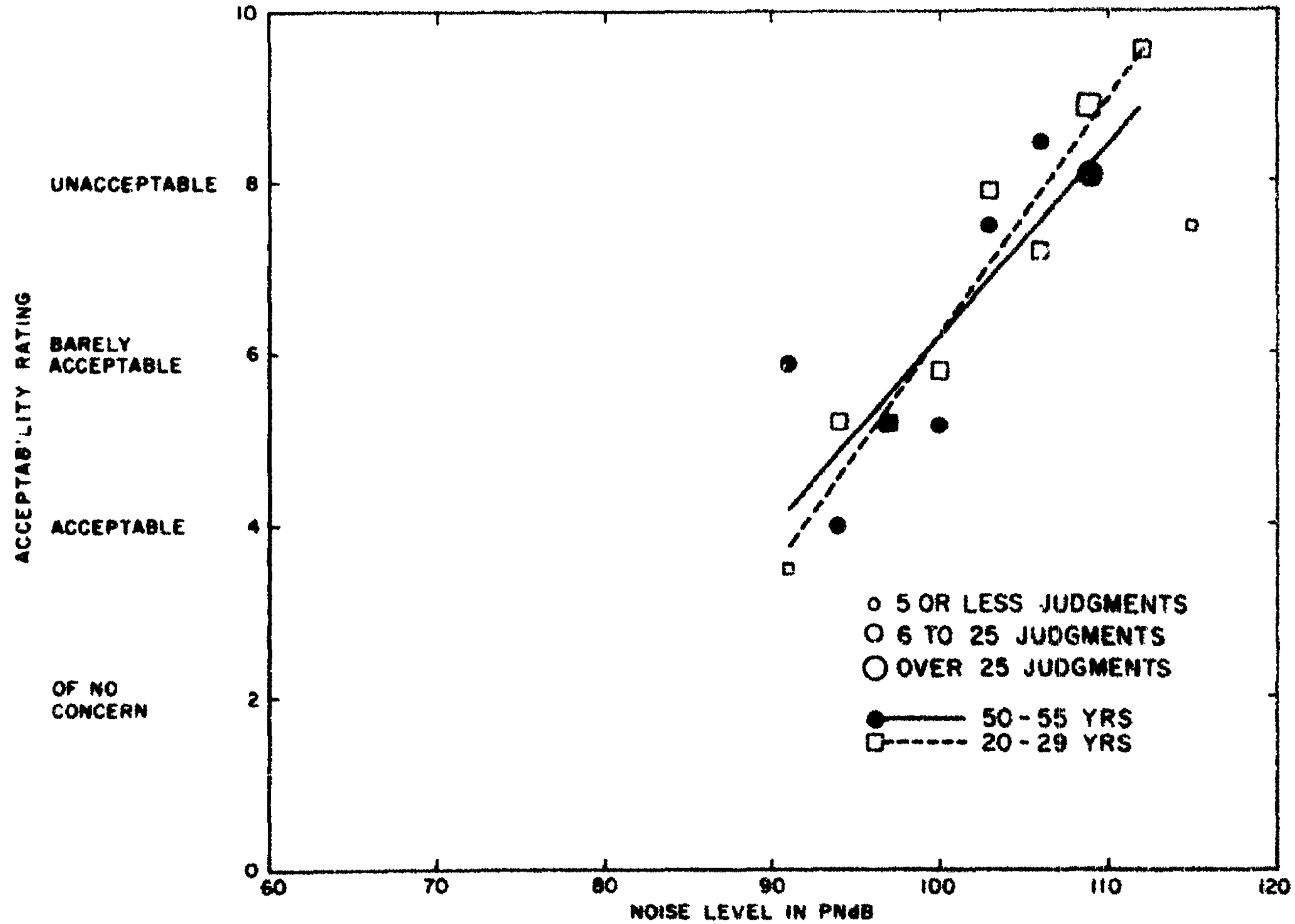


FIGURE 19. MEDIAN ACCEPTABILITY RATINGS – ACTUAL APPROACH FLYOVERS HEARD OUTSIDE – 20-29 YRS VS 50-55 YRS

agreement between age groups is very close and only a single weighted regression line has been fitted to the data. In Figs. 18 and 19, showing results for judgments of actual approach flyovers, small differences between age groups occurred.

On the basis of these test results, therefore, one may conclude that for the subjects studied there were no large differences in judgments between men and women or between the different age groups. These results are consistent with those found in the British tests where differences due to age and sex were found to be small.

2) <u>Type of Aircraft</u>

During the flyover judgment tests, aircraft were identified only as jet (turbojet and turbofan) and propeller (piston and turbine). Thus, no detailed breakdown of judgment comparisons versus aircraft type could be conducted. Only a few propeller aircraft takeoffs were judged. However, as Fig. 2 shows, an appreciable number of approach flyovers were made by propeller aircraft. Thus, some comparison of judgments of propeller and jet approach noise is possible.

Unfortunately, the noise levels produced by propeller aircraft were primarily in the lower part of the dynamic range while the noise from jet aircraft fell primarily in the upper portion of the dynamic range; consequently there was only a limited mid-range of levels in which comparable numbers of jet and propeller aircraft were judged. Comparison of the judgments in this limited range shows, with considerable scatter, that there was a tendency for the propeller aircraft to be judged more acceptable than the jet aircraft for the same flyover noise level. However, statistical tests applied to these data show that these differences in rating propeller aircraft and jet aircraft are not generally significant at the 5% level. Thus, on the basis of this relatively incomplete comparison, one must conclude that there was no statistically significant difference in the absolute acceptability ratings of approach noise produced by propeller aircraft and that produced by jet aircraft.

IV. RELATIVE ACCEPTABILITY JUDGMENTS

In the analysis of Tests 1 and 2, scores were first sorted according to the difference in PNdB between the test fly-over and the reference flyover. The geometric mean of the scores in each 3 PNdB interval was then determined.* Figures 20, 21 and 22 show the geometric mean of the test scores plotted against the difference between test flyover noise level and reference flyover level. Figure 20 shows the geometric mean scores for takeoff noise heard indoors. Two curves are shown, one for the bedroom test in which actual flyovers were used as a reference, and one for the living room test in which a recorded flyover was the reference. Similarily, Fig. 21 shows two curves for indoor judgments of approach noise. Figure 22 compares the geometric mean scores for the outdoor observations; separate curves are shown for takeoff and approach fly-overs.

It can be noted from these figures that, in general, the dynamic test range extends further to negative values of differences between test flyovers and reference flyovers than to positive values. This results from a choice of reference flyovers that were, on the average, slightly higher in level than the mean of the flyovers encountered during the tests. Table IV lists the arithmetic mean value and range of noise levels for the reference flyovers used in the different tests.

---

* In accordance with one of the hypothesis for Tests 1 and 2, we would expect the subjective ratings plotted on a logarithmic scale to have a linear relationship with the perceived noise levels. The arithmetic mean of the logarithms of the scores in a given PNdB interval is equal to the logarithm of the geometric mean of all the scores in the interval.

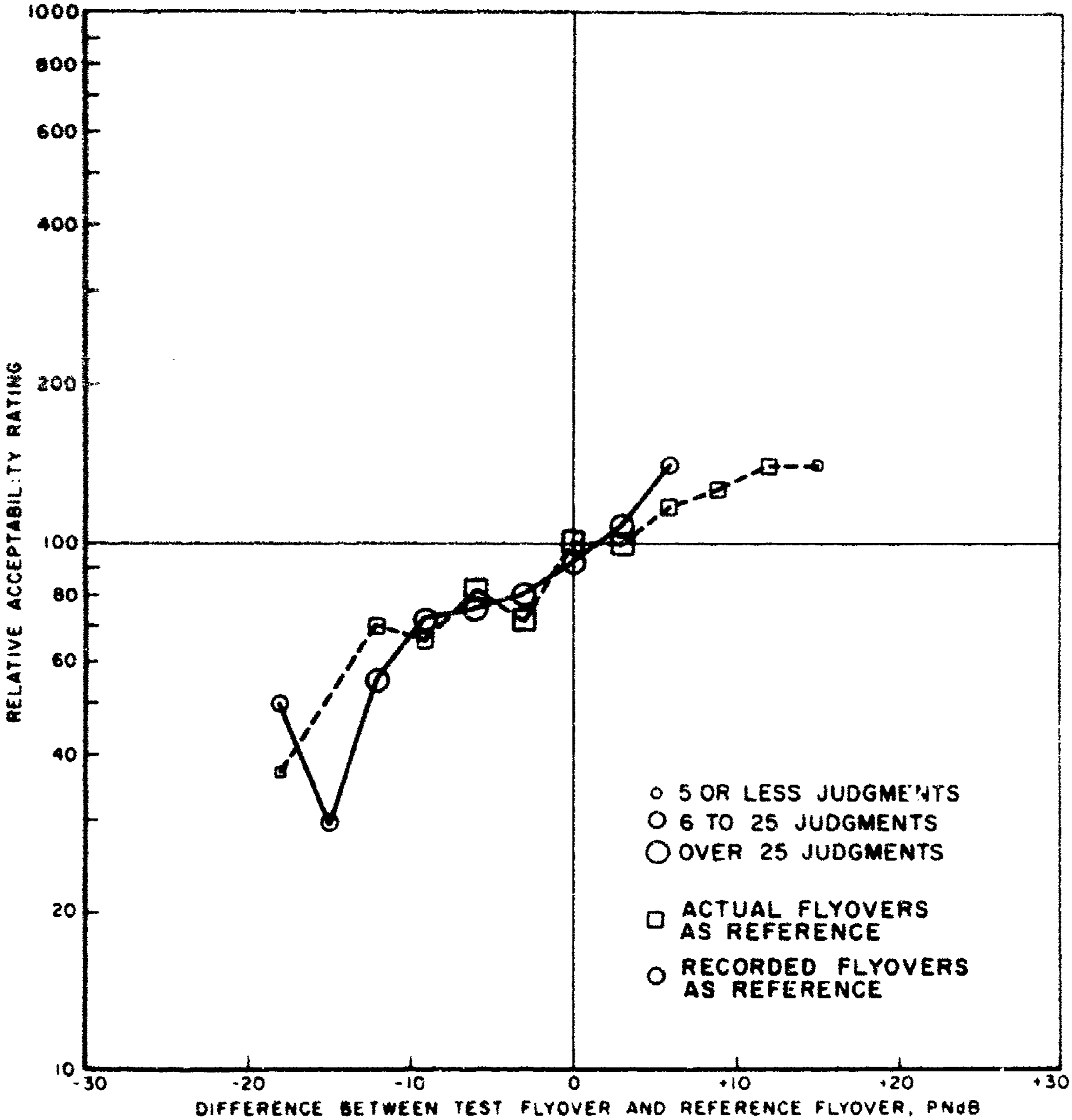


FIGURE 20. GEOMETRIC MEAN SCORES FOR RELATIVE ACCEPTABILITY RATINGS OF TAKEOFF NOISE, HEARD INDOORS

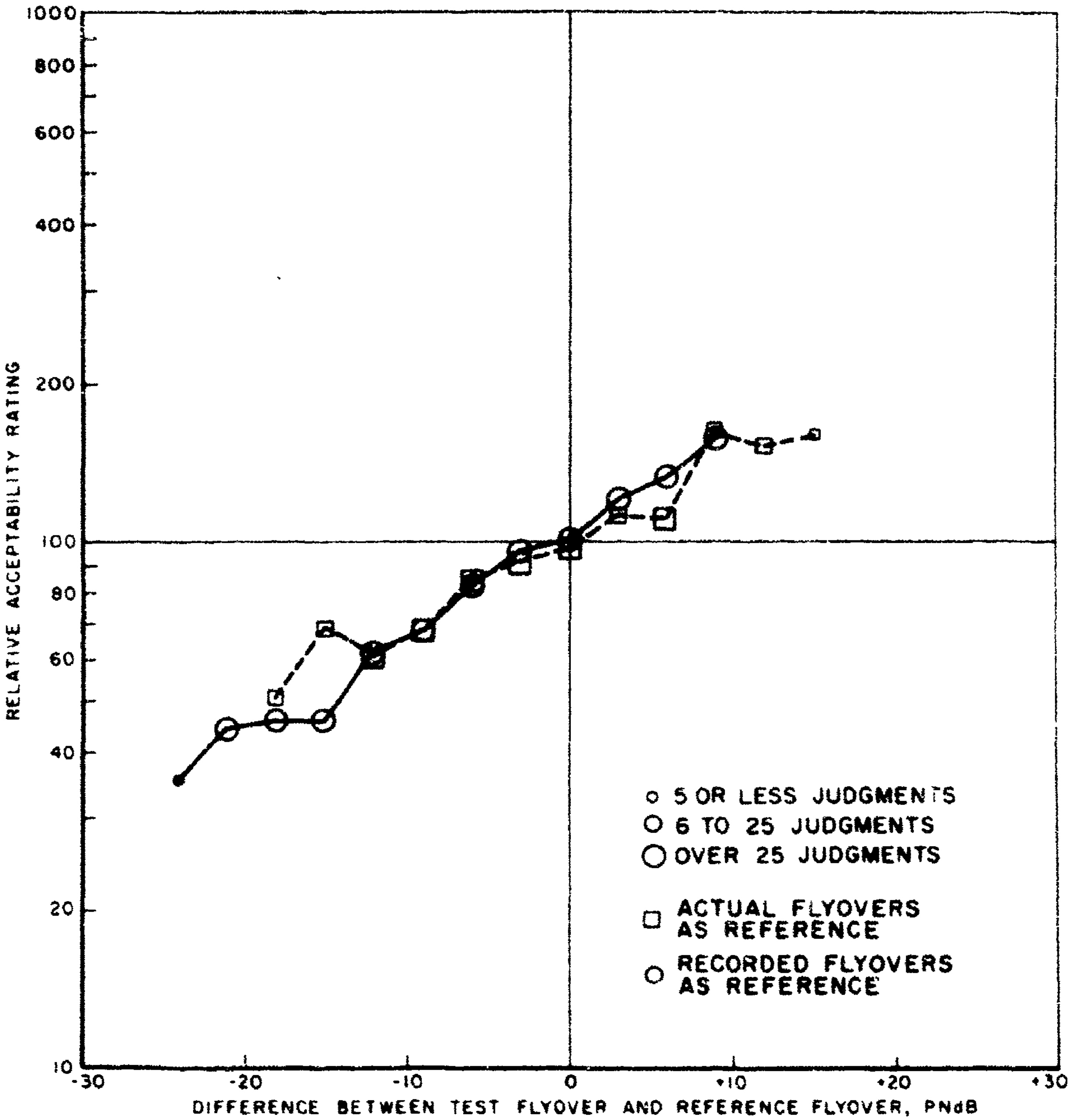


FIGURE 21. GEOMETRIC MEAN SCORES FOR RELATIVE ACCEPTABILITY RATINGS OF APPROACH NOISE, HEARD INDOORS

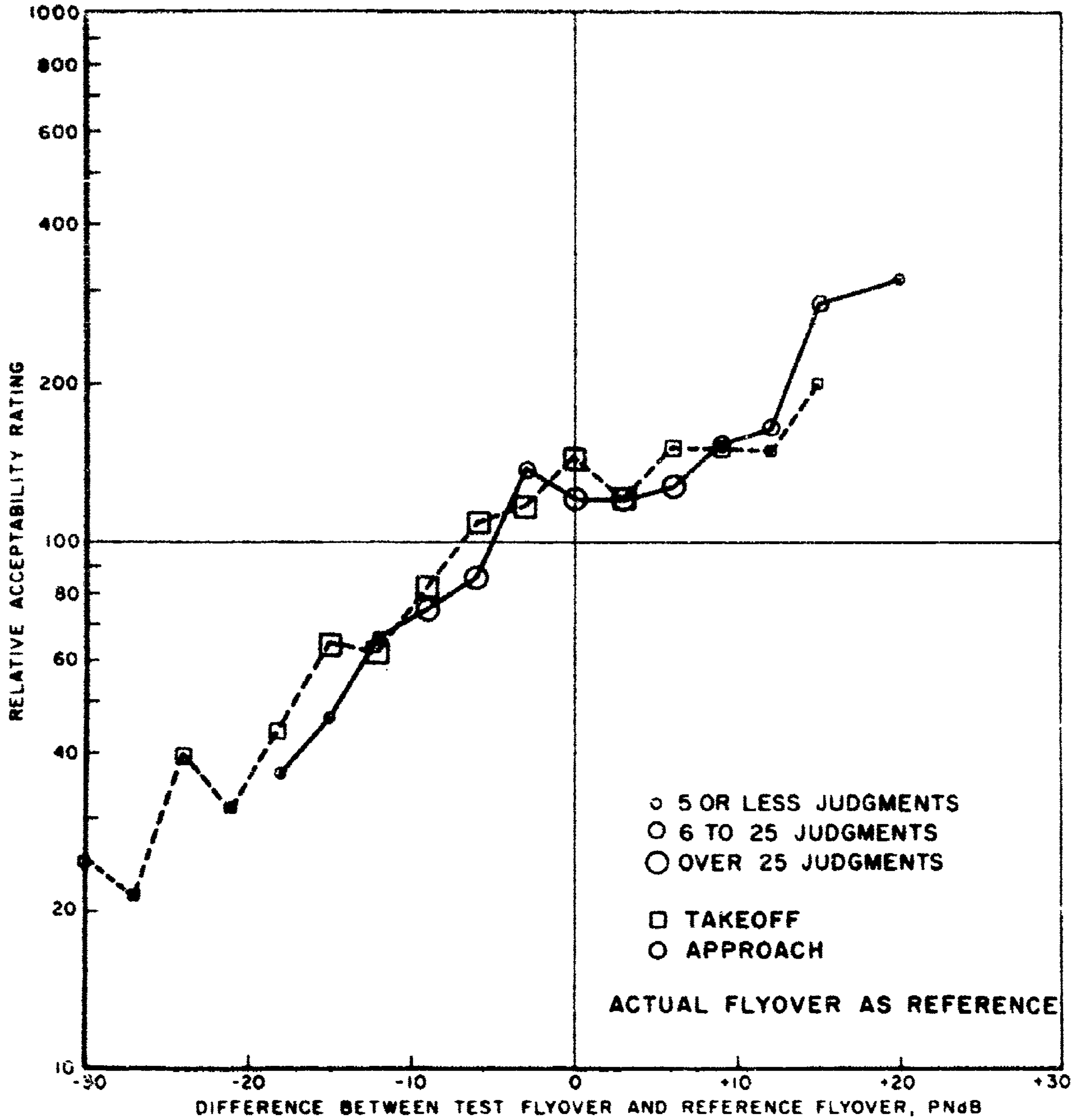


FIGURE 22. GEOMETRIC MEAN SCORES FOR RELATIVE ACCEPTABILITY RATINGS OF TAKEOFF AND APPROACH NOISE, HEARD OUTDOORS

TABLE IV

MEAN AND RANGE OF FLYOVER NOISE LEVELS
USED AS REFERENCES IN TESTS 1 AND 2

NOISE SIGNAL		Reference Noise Levels in PNdB			
		Indoors		Outdoors	
		Mean	Range	Mean	Range
Takeoff	Actual	80	73-86	104	97-117
	Recorded	87	85-88		
Approach	Actual	82	70-90	108	101-113
	Recorded	87	85-90		

Comparison of curves in Figs. 20 and 21 shows that:

a) There is little difference in geometric mean scores between judgments using actual flyovers as a reference, and those using recorded flyovers as a reference.

b) There is little difference between geometric scores of approach noise and those of takeoff noise.

c) The curves in Figs. 20 and 21 show an approximate relative acceptability rating of 100 when the difference between test flyover and reference flyover was 0 PNdB.

Figure 22 shows, consistent with the indoor judgments, that there is little difference in geometric mean scores for

judgments of takeoff noise or of approach noise. However, in contrast to the indoor judgments, the outdoor scores show that for a relative acceptability rating of 100 the difference between test flyover and reference flyover ranges between -5 to -8 PNdB. (Or, alternatively, one may state that for a test flyover of the same perceived noise level as the reference flyover, subjects rated the test flyover noisier than the reference, with the geometric mean ratings ranging from approximately 120 to 145.) One may also observe that while the indoor scores could be well approximated by a straight line, there is a slight indication of curvature in the geometric mean scores for the flyovers heard outdoors.

Because of the generally small differences between geometric mean scores for the indoor judgments and those for the outdoor judgments, all indoor and all outdoor scores were combined. Figure 23 shows the geometric mean scores for the combined indoor scores and for the combined outdoor scores. Straight line weighted regression curves have been fitted to the data.

As can be seen from Fig. 23, the slopes of the two curves are the same. However, the intercepts differ; while the indoor scores show a relative acceptability rating of 100 for a test flyover of the same level as the reference flyover, the outdoor curve shows a relative acceptability rating well above 100 for a test flyover of the same level as the reference. A statistical check* of the relative judgment data for differences between the test flyover and reference flyover shows the differences between the outdoor and indoor geometric mean relative acceptability ratings to be significant at the 1% level.

The slope of the regression lines fitted to the geometric mean scores indicates that an increase of approximately 16 PNdB is required for a doubling of the noisiness or

---

* Application of t test, Reference 10.

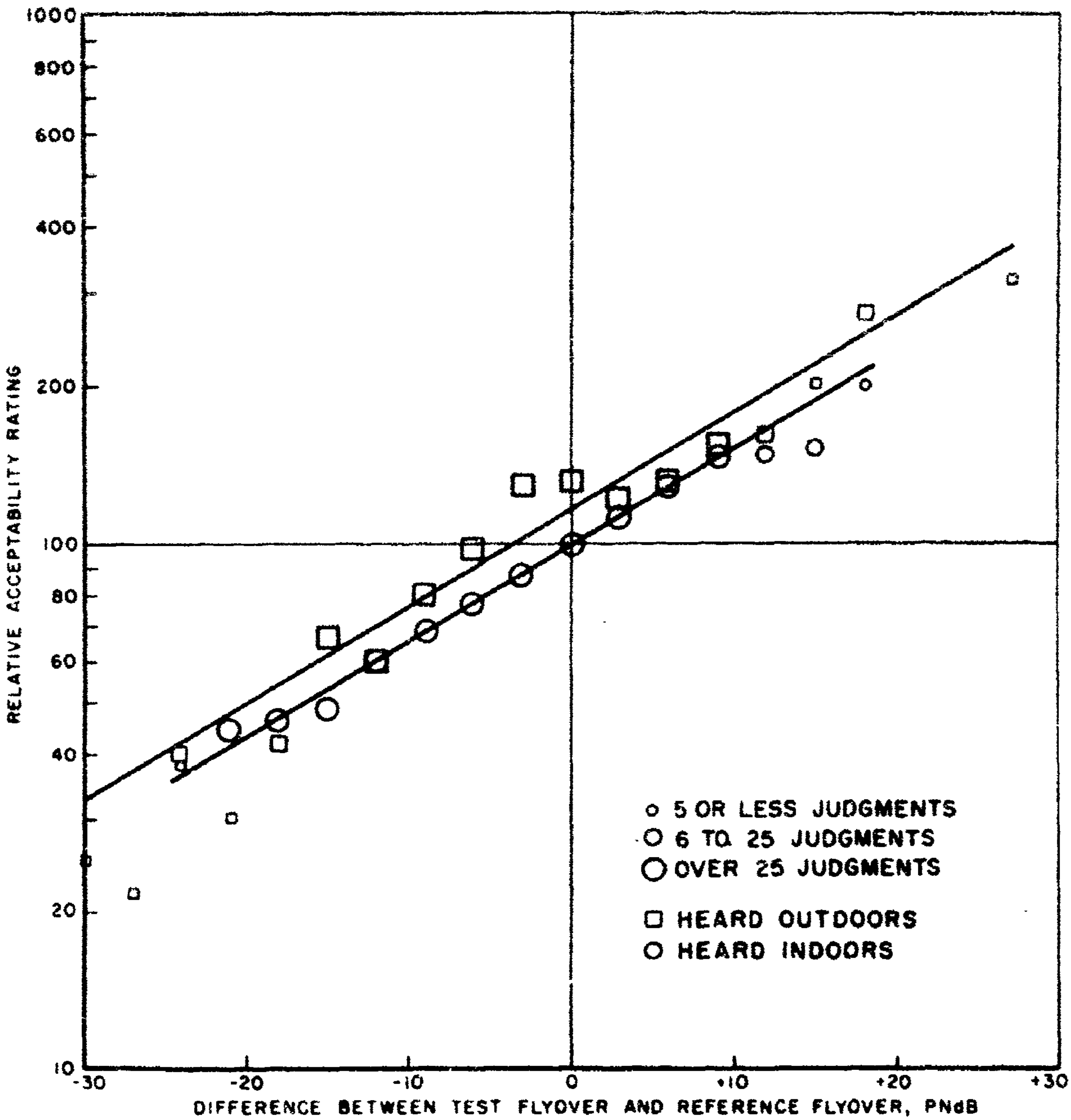


FIGURE 23. GEOMETRIC MEAN SCORES FOR RELATIVE ACCEPTABILITY RATINGS OF FLYOVER NOISE—COMBINED TAKEOFF AND APPROACH SCORES

acceptability rating. This value is considerably greater than the 10 PNdB for a doubling in noisiness assumed in deriving the perceived noise level scale. (The value of 10 PNdB for a doubling of noisiness is based upon the original assumption by Kryter that the perceived noisiness of a sound grows as a function of physical intensity at the same rate that loudness increases with intensity.1/ And Stevens has previously shown that a reasonable value for a doubling in loudness was 10 PNdB.)15,16/

The assumption that a 10 PNdB change in noise level results in a 2 to 1 change in relative noisiness or annoyance has never been directly tested in the laboratory. However, results from recent British tests,17/ in which subjects were asked to estimate the relative annoyance of the sounds of jet aircraft, piston aircraft, and sonic booms at different levels indicate that a change in sound pressure level of just under 13 dB was needed to double the annoyance of the aircraft sounds.

The difference in intercepts between outdoor and indoor judgments, clearly evident from Fig. 23, is in accordance with a frequently encountered source of distortion in noisiness or loudness judgment tests.1,15/

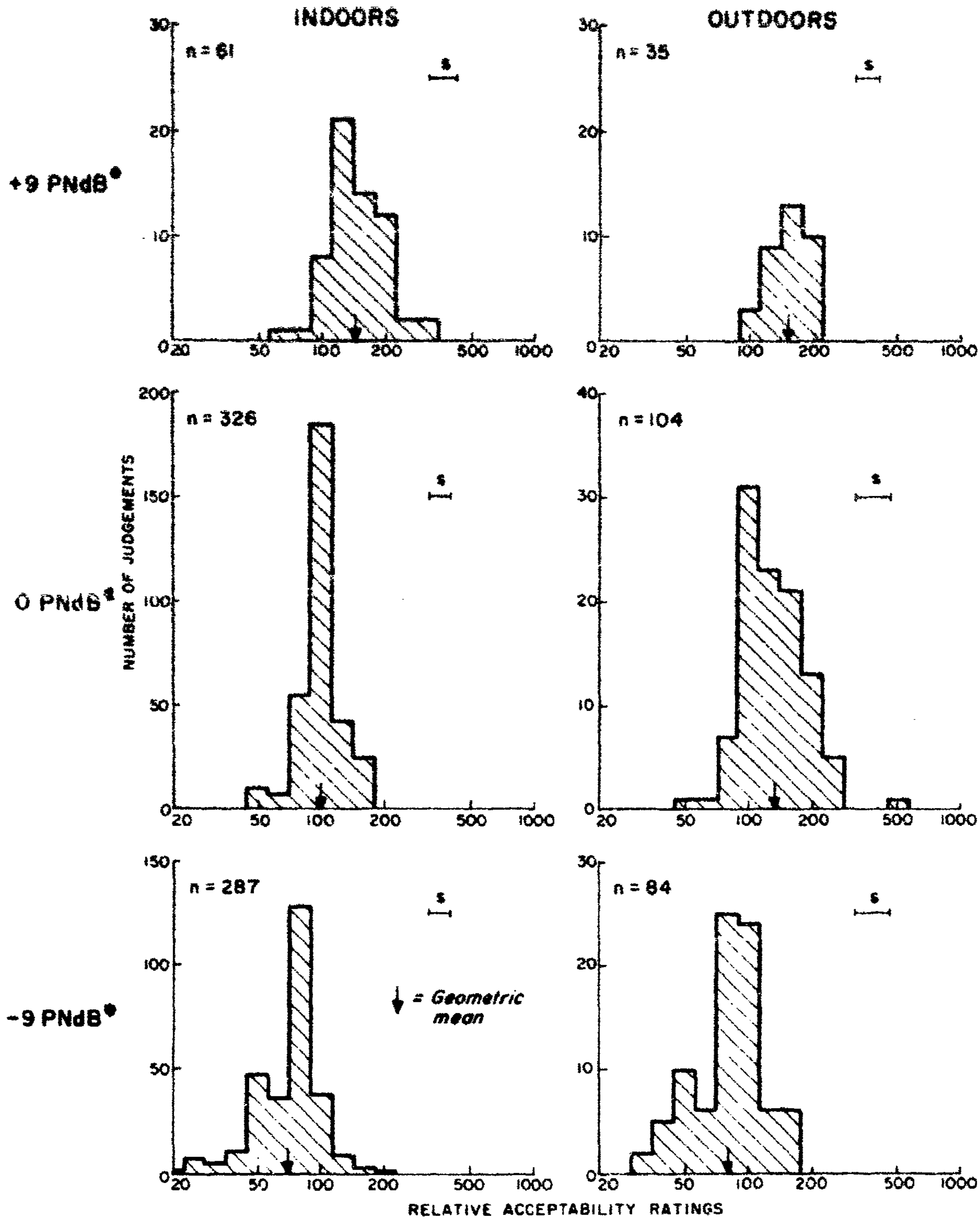
This distortion, or "time error", arises from a preference of most subjects for listening to moderate levels of noise. Thus subjects may tend to overestimate the noisiness of high intensity sounds, and to underestimate the noisiness of low intensity sounds. In making paired comparison judgments it is often observed the second signal will be judged noisier than the first signal, even though both are physically equal in level provided the noise levels are relatively intense (order of 95 PNdB or greater). When the listening levels are low, the time error reverses and the second signal in a pair may be judged less noisy than the reference signal when both are physically equal. At moderate playback levels, the time error is of small magnitude. The present results are consistent with what one would expect from this behavior, since the displacement of intercepts occurs only in the outdoor judgment tests, where reference and test levels were quite high.

Like the absolute judgment tests, there is considerable dispersion in the relative rating scores. As an indication of this dispersion, Fig. 24 shows a few histograms of the combined indoor and combined outdoor judgments. Histograms are shown for three differences between test flyovers and reference flyovers, -9, 0 and +9 PNdB. One may note the differences in total number of judgments recorded indoors and outdoors and at the different levels. Also to be noted is the fact that the value of standard deviation, s, is relatively constant for the histograms shown.

The standard deviation for these tests, when expressed in percent, is quite high. For example, the rms value of the standard deviations observed for the various differences between test and reference flyovers was 51% for the combined indoor judgments and 44% for the combined outdoor judgments.

Results of another method of interpreting the judgment scores in which relative dispersion between tests can be more easily compared, are shown in Figs. 25, 26 and 27. In this interpretation, test scores were analyzed in terms of whether the individual test item ratings were greater than, equal to, or less than the reference rating of 100. These scores were then grouped according to the difference between test flyover and referency flyover noise levels. The percentage of test scores above 100 was then plotted as a function of the difference between test flyover and reference flyover levels. Now, in many cases, scores of 100 were recorded by the subjects. In preparing the figures, half of the amount of 100 scores were added to the number of ratings greater than 100 and half were added to the number of ratings less than 100.

Figure 25 shows the results for the three approach noise tests; similarly, Fig. 26 shows the results for the three takeoff noise tests. Figure 27 has two curves giving the results of the combined outdoor judgments and the combined indoor judgments.



* DIFFERENCE BETWEEN TEST FLYOVER AND REFERENCE FLYOVER

FIGURE 24. TYPICAL HISTOGRAMS OF RELATIVE ACCEPTABILITY RATINGS–COMBINED SCORES FOR APPROACH AND TAKEOFF NOISE

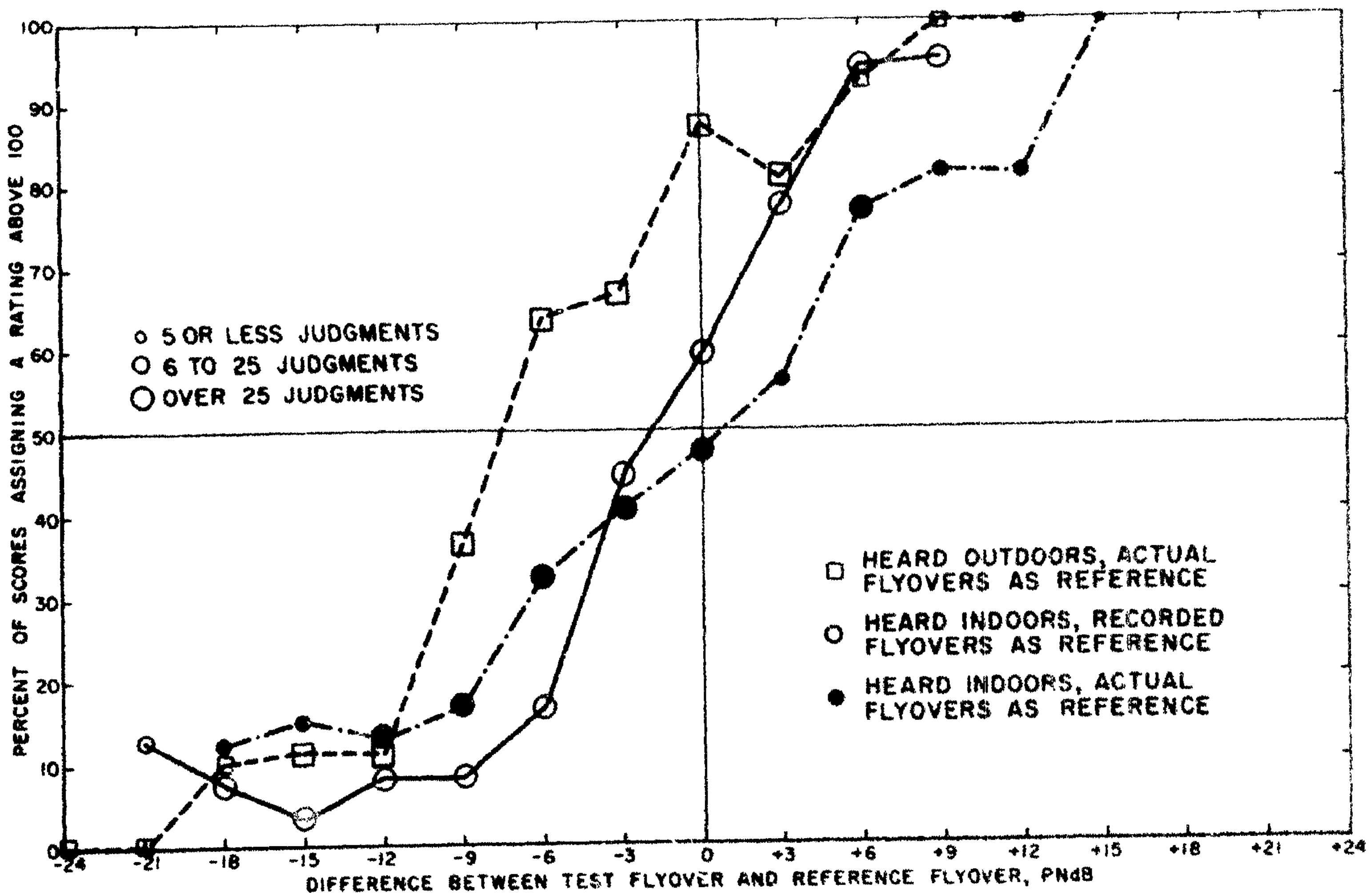


FIGURE 25. PERCENT OF SCORES RATING TEST FLYOVER NOISIER THAN REFERENCE FLYOVER – APPROACH NOISE

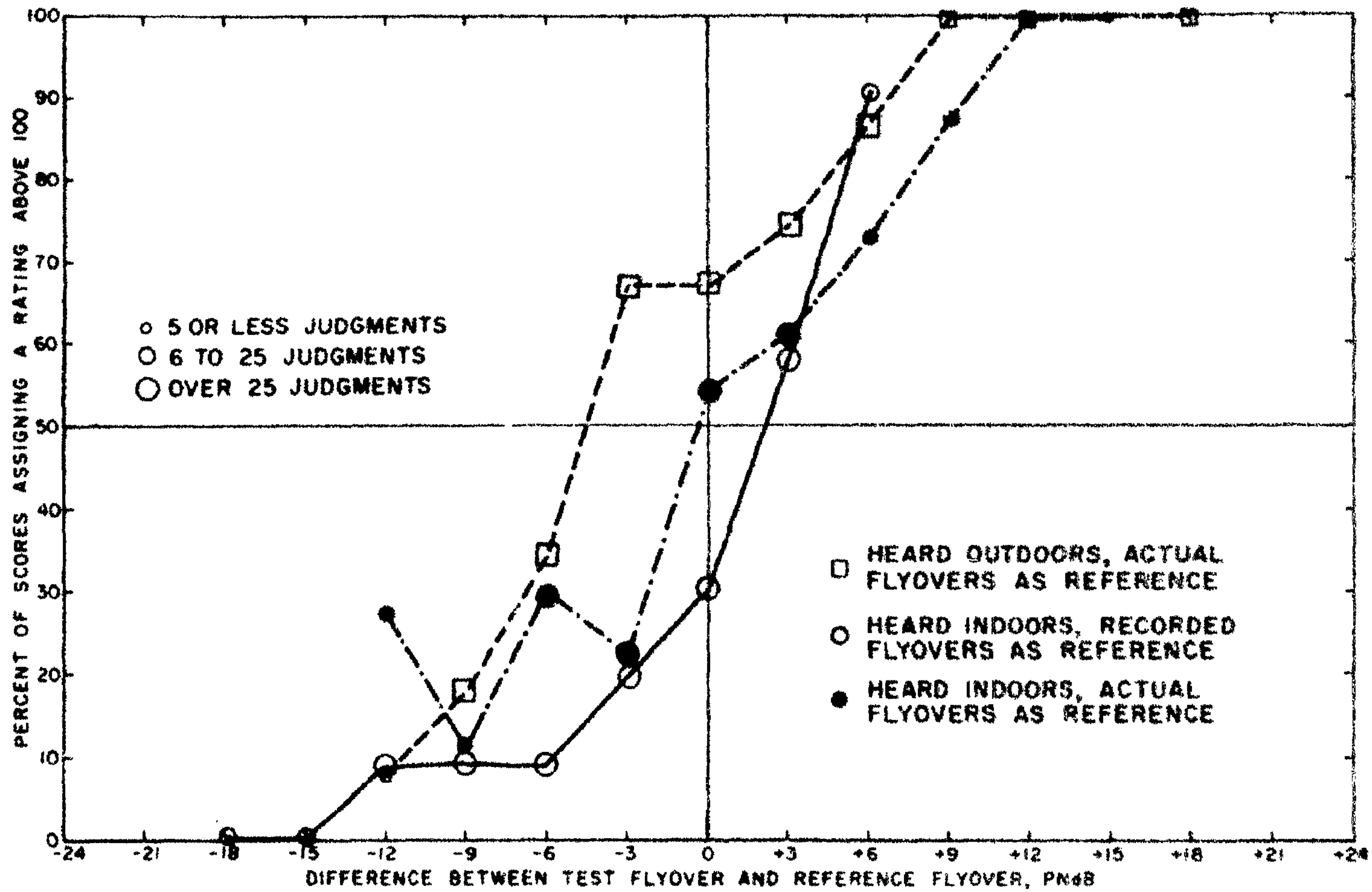


FIGURE 26. PERCENT OF SCORES RATING TEST FLYOVER NOISIER THAN REFERENCE FLYOVER – TAKEOFF NOISE

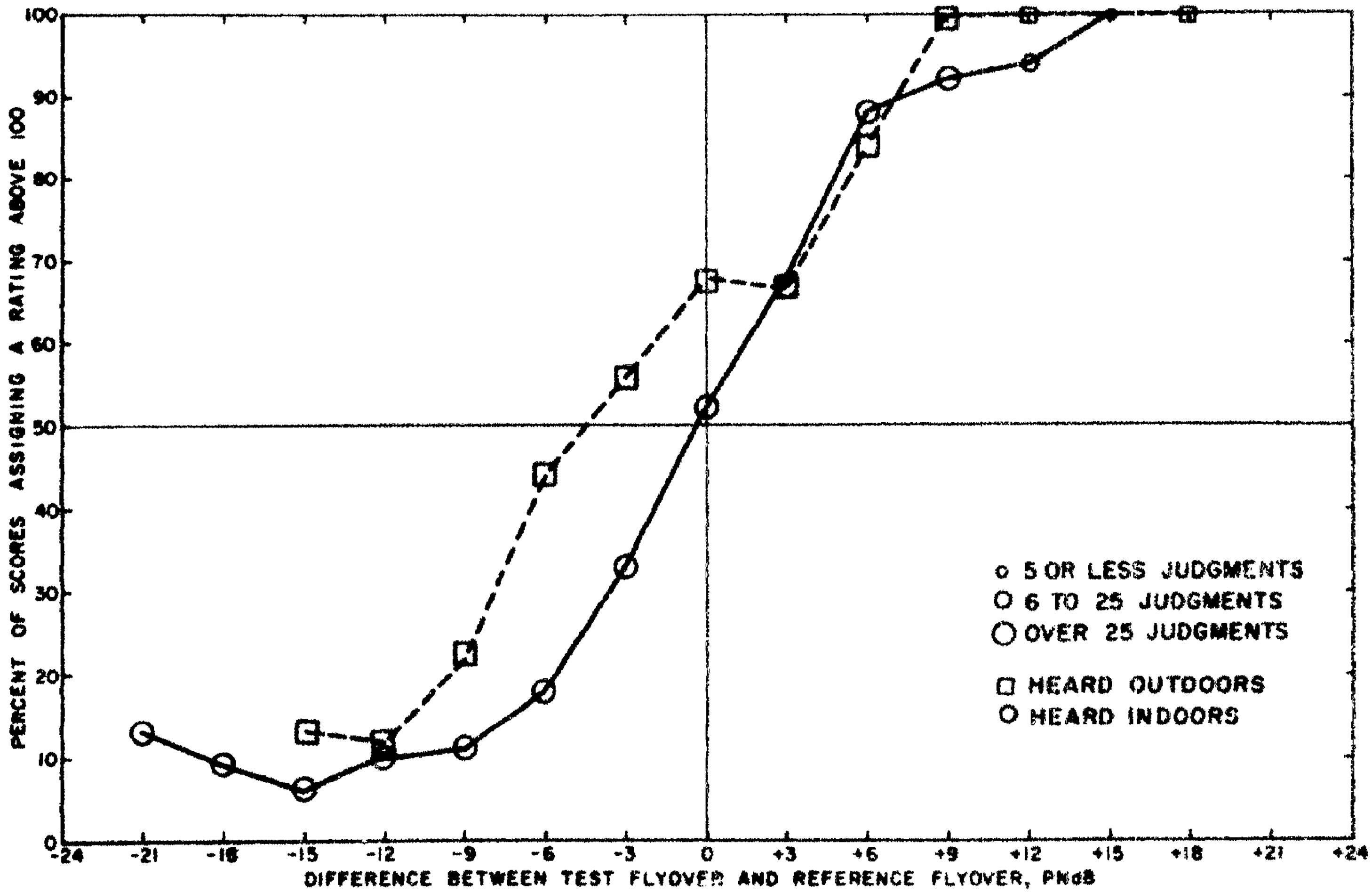


FIGURE 27. PERCENT OF SCORES RATING TEST FLYOVER NOISIER THAN REFERENCE FLYOVER – COMBINED APPROACH AND TAKEOFF SCORES

In this type of presentation, one assumes that the two noise signals are equal in noisiness or acceptability when the percentage of scores above 100 equals 50%, (i.e., when judgments are equally divided as to whether the test item is more noisy or less noisy than the reference signal). Reference to the figures indicates that for the indoor judgments (approach and takeoff noise with either recorded or actual flyovers as reference) the 50% line is reached when the difference between test flyover and reference flyover is within ±3 PNdB. However, the outdoor judgment curves are displaced to the left so that the curves cross the 50% line at differences ranging from -5 to -9 PNdB. This shift to the left for the outdoor judgment curves is, of course, consistent with the displacement earlier observed for the ratio scale results, and results from the time error discussed earlier.

One method of analyzing the test results which effectively eliminates the time error is to look at the successive judgments in terms of whether or not the rating of each successive test flyover was greater, equal, or less than the rating of the immediately preceding flyover. These scores were then tabulated in terms of the difference between the test flyover level and the previous flyover level, regardless of whether the previous flyover was a reference or a test item. The results of the analysis, grouping all outdoor judgments and grouping all indoor judgments, is shown in the two curves of Fig. 28. Both curves cross the 50% line for a difference between test flyover and preceding flyover of near 0 PNdB. The two curves also agreed quite closely in shape throughout the dynamic range.

The curves shown in Figs. 25 through 28 also permit comparison of the relative sensitivity of the various tests in indicating changes in judgment with changes in perceived noise level. This indication of test sensitivity is provided through comparison of the curve slopes in the mid-scale intervals. Thus, a test curve whose slope in the vicinity of the 50% score is steep would indicate

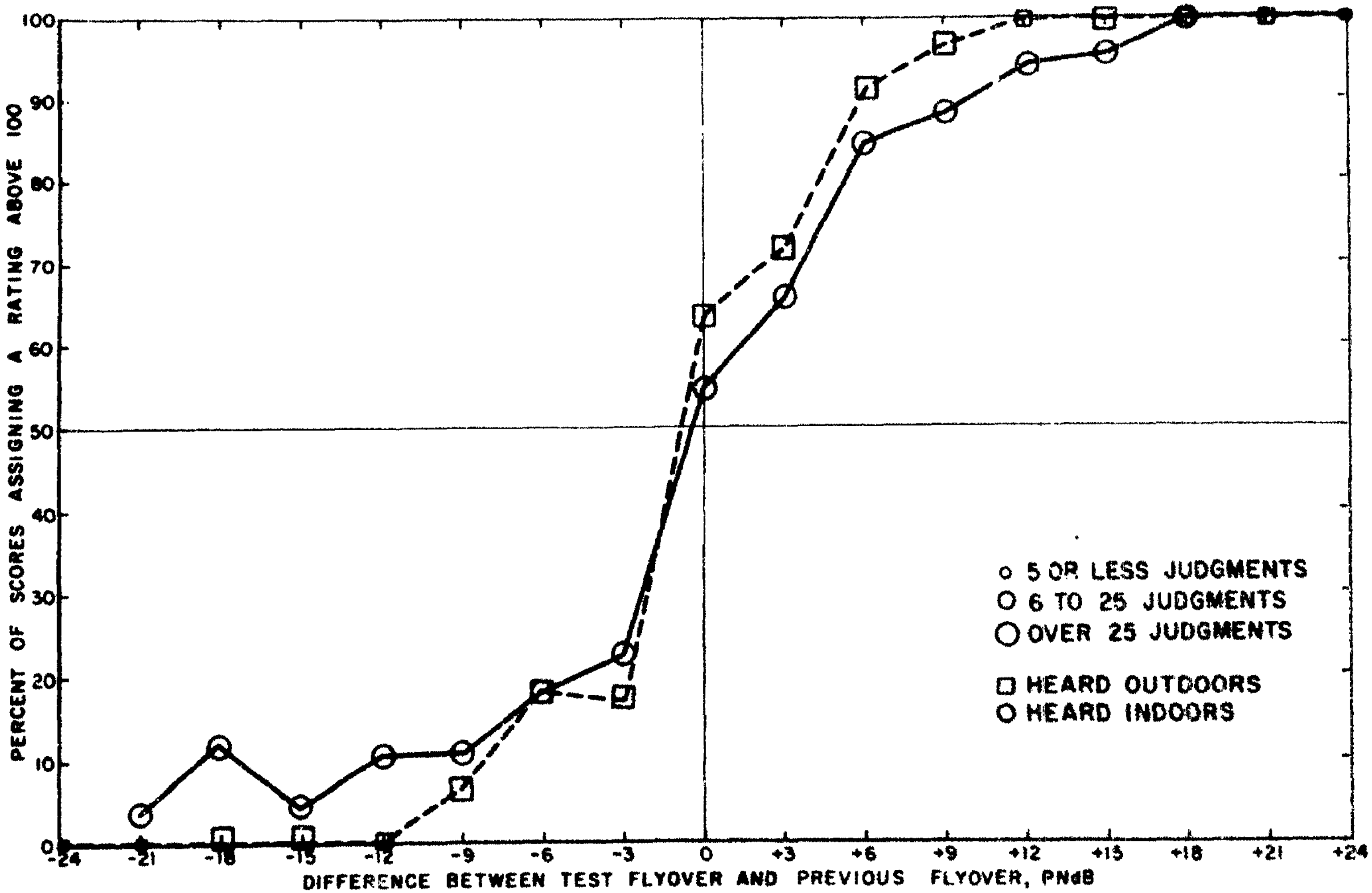


FIGURE 28. PERCENT OF SCORES RATING TEST FLYOVER NOISIER THAN PREVIOUS FLYOVER — COMBINED APPROACH AND TAKEOFF SCORES

a sensitive test in which a small increase (decrease) in level between test flyover and reference flyover resulted in a large increase (decrease) in the percent of judgments rating the test flyover noisier than the reference flyover.

The slope is, of course, determined by dispersion resulting not only from test procedures and test administration, but also from subject variability and subject consistency. However, if one assumes subject variability and consistency to be the same for the different tests, significant variations in test curve slopes can be assigned to differences between tests.

To provide an approximate but consistent measure of the slopes of the various curves, the data from Figs. 25 through 28 were plotted on probability paper. Straight lines were then fitted to each set of data by eye and standard deviations determined. The standard deviation thus determined and expressed in PNdB, measures the reciprocal of the curve slope. The standard deviation values are tabulated in Table V.

The values of standard deviation for the takeoff judgment tests are each slightly smaller than those for corresponding approach tests. Perhaps most interesting is the comparison between the inside tests using recorded flyovers as a reference and those with actual flyovers as a reference. For both takeoff and approach judgments, the standard deviations for the recorded reference tests are considerably smaller than those with the actual flyovers as a reference. This result might be expected since the recorded reference was played back after each test flyover while, for tests using an actual flyover reference, the reference was heard only once at the beginning of the test session. Comparison of the combined test results shows, as might be expected from comparison of Figs. 27 and 28, that the standard deviations are smallest when the previous flyover is taken as a reference.

TABLE V

COMPARISON OF STANDARD DEVIATIONS FOR CURVES

SHOWING PERCENT OF JUDGMENTS RATING TEST

FLYOVER NOISIER THAN REFERENCE FLYOVER

Test Signal	Reference Flyover	Standard Deviation PNdB
Takeoff - Heard Indoors	Recorded (1)	4.1
	Actual (2)	7.4
- Heard Outdoors	Actual (2)	6.7
Approach - Heard Indoors	Recorded (1)	5.3
	Actual (2)	10.3
- Heard Outdoors	Actual (2)	7.3
Combined Takeoff and Approach - Heard Indoors	Recorded (1) and Actual (2)	6.5
- Heard Outdoors	Actual (2)	7.5
Combined Takeoff and Approach - Heard Indoors	Recorded and Actual (3)	5.9
- Heard Outdoors	Actual (3)	5.0

Notes: (1) Reference played at beginning of test session and immediately following each test item.

(2) Reference taken as first actual flyover in test session.

(3) Preceeding flyover as reference.

V. CONCLUSIONS

Analysis of the results of the judgment tests involving both relative and absolute ratings of the acceptability of aircraft noise, leads to the following conclusions:

1) For indoor judgments, the correlation between an absolute acceptability rating scale and maximum fly-over noise level expressed in PNdB was essentially the same regardless of whether the subjects listened to approach noise or takeoff noise or whether they listened to actual flyovers or recorded flyovers. Thus, for a median subjective rating of "barely acceptable," the perceived noise level ranged from 82 to 86.5 PNdB for the various indoor tests with a mean for the four tests of 85.5 PNdB.

2) For outdoor judgments there was no significant difference in the correlation between subjective rating and perceived noise level when listening to either approach noise or takeoff noise.

3) For the same acceptability rating there was a sizeable displacement in the correlation curves between indoor judgments and outdoor judgments. This displacement amounted to about 14 PNdB at mid-scale. It means that a similar degree of acceptability will be assigned to a flyover heard indoors that is less in maximum level than a flyover heard outdoors. This displacement value was less in magnitude than the noise reduction (21 to 24 PNdB) provided by the test building structures.

4) No significant differences in the correlation between acceptability ratings and perceived noise levels were found in the judgments of men and women or younger and older age groups. In judging approach noise, some tendency was found for subjects to judge noise from jet aircraft flyovers as less acceptable than noise from propeller aircraft flyovers of the same perceived noise level.

5) There was considerable dispersion in the acceptability ratings of flyover noise. However, the dispersion did not differ significantly among the different tests. The four major sources of variability for the absolute judgment tests could be ranked in the following order of decreasing importance:

1. Lack of consistency in individual subject ratings.

2. Differences between subjects.

3. Lack of correspondence between objective measurement scales and subjective measurement scales.

4. Objective measurement errors.

Estimated values for the first three items were approximately the same, while the standard deviation for the last was considerably smaller than the others. Because of the similar magnitude of the first three sources of variability, refinement of the objective measurement scale to reduce the variability due to differences between objective and subjective measurement scales would not lead to a significant reduction of total test variability.

6) For the relative judgment tests made indoors, in which subjects rated aircraft noise in terms of a number larger than, equal to, or smaller than a number assigned to the noise of a reference flyover, it was found that the correlation between judgment scores and differences between test flyover level and reference flyover level was essentially the same, regardless of whether subjects rated approach noise or takeoff noise or whether they rated flyover noise using recorded or actual flyover signals as a reference.

7) For similar tests conducted outdoors, using actual flyovers as a reference, there was little significant difference between judgments of approach or takeoff noise.

8) For both outdoor and indoor relative judgments the slopes of the regression lines (fitted to the geometric mean scores) relating acceptability ratings and differences between test and reference flyover levels were the same. The slopes indicate a change of 16 PNdB is required for a doubling of noisiness. This value is much larger than the 10 PNdB for doubling of noisiness originally assumed in development of the perceived noise level scale.

9) The difference in intercepts between outdoor and indoor curves relating relative ratings, to the difference between test flyovers and reference flyovers can be satisfactorily explained by the time error, resulting from a preference of subjects to listen to moderate levels of noise.

10) A slight increase in test sensitivity, (interpreted as a slight reduction in the difference between test flyover and reference flyover noise levels required to produce a given change in percent of relative rating scores above or below the reference score of 100) was observed from the indoor tests in which a recorded flyover signal was the reference. This increase in test sensitivity, as compared to tests in which noise from actual flyovers were a reference, may reasonably be attributed to the repitition of the reference signal in tests using a recorded reference.

11) A comparison of perceived noise levels calculated from octave band noise spectra and values estimated from single network levels (dBA and Perceived Noise Level networks) shows the dBA and PNL network values provide estimates of about equal variability. The variability provided by use of either network is small compared to the total test dispersion.

VI. RECOMMENDATIONS

A. Differences Between Takeoff and Approach Noise Judgments

These tests show that the subjective ratings of approach flyover noise and takeoff flyover noise may be correlated, with equal precision, with the maximum perceived noise level observed during the flyovers. Little difference was observed between approach and flyover judgments even though the approach flyovers had, on the average, significantly shorter time durations than the takeoff flyovers. These results, then, suggest that the possible changes in noisiness ratings produced by differences in flyover signal time duration, or by presence of strong pure tone components in the flyover signal:

are compensating factors in making compositive noisiness judgments of approach and takeoff noise; or, possibly,

are not factors of large enough magnitude to require consideration in evaluating flyover noise signals of current jet aircraft.

There is clearly need for further study to determine the extent to which differences in time duration and in pure tone content are to be taken into account in rating the noise of actual jet aircraft flyovers. Future study should include both judgment tests and detailed objective analysis of typical flyover signals. Relative noisiness judgment tests of recordings of a variety of takeoff and approach noise signals should be conducted. Accompanying these tests should be a review of methods for analyzing complex, non-stationary time signals to develop meaningful measures of determining time duration and the presence and magnitude of pure tone components in real-life flyover signals.

From the refined methods of analyzing flyover noise signals and the results of existing laboratory tests examining the influence of time duration and pure tone components, tentative corrections for time duration

and pure tone components can then be developed and applied to the noise signals used in the judgment tests. Comparisons of judgments, with the modified objective measures of the noise stimulus, should then reveal whether or not improved correlation between subjective and objective ratings are obtained when pure tone and duration factors are taken into account.

B. Growth of Perceived Noisiness as a Function of Physical Intensity

The current tests indicate that a change in perceived noise levels of about 16 PNdB is needed to cause a doubling or halving of the judged noisiness or acceptability of the flyover signal. This value for doubling or halving of noisiness is much larger than the 10 PNdB originally assumed in developing the noisiness scale. This difference suggests the need for formal laboratory tests, particularly since the original assumption of 10 PNdB for doubling has never been subjected to laboratory validation. Such a laboratory investigation should include not only aircraft sounds but also various other steady-state noise signals to permit one of the basic assumptions of the perceived noise level scale to be thoroughly checked.

C. Differences in Subjective Ratings of Noise Heard Outdoors and Indoors

These tests, as did the somewhat similar British tests, disclosed significant differences in subjective ratings of noise heard outdoors and indoors. Over the relatively limited dynamic range experienced in the present tests two correlation curves, one displaced from the other, were needed to describe absolute acceptability ratings of aircraft noise. One would, however, expect the separate correlation curves for indoor and outdoor judgments to approach and merge at both very high and very low noise levels. The extent to which this expectation is valid requires exploration by further outdoor and indoor judgments of actual flyover noise conducted over a wider dynamic range than experienced in these tests.

One possible explanation for the differences between outdoor and indoor judgments is that subjects make an allowance, presumably unconsciously, for the reduction of sound afforded by building structures.7/ Questions arise as to whether or not such an allowance is based primarily upon a subject's past experience and whether or not the subject's allowance is also influenced by his expectation of what the noise reduction should be in a particular building. To explore these questions, further absolute judgment tests should be conducted of flyover noise heard inside structures having different (or apparently different to the subject) degrees of noise reduction.

D. Further Exploration of Absolute Rating Scales

The present tests were conducted with a group of people having roughly similar previous exposure to aircraft noise. Whether different groups of people, having much different histories of exposure to aircraft noise, would rate aircraft noise according to the same absolute rating scale was not explored. To answer this question additional tests with groups of subjects having widely different histories of exposure to aircraft noise are obviously needed. However, for many practical applications, this question of relative response of subjects having widely different exposure to noise may be somewhat academic. Generally, where one is concerned with evaluating noise with respect to response in actual airport/community noise situations, some degree of conditioning and exposure to noise can reasonably be assumed for the people most likely to be affected by aircraft noise. One is obviously most concerned with developing scales or limits for people who will be or have been exposed to the noise, not for people who will never or rarely encounter the noise stimulus.

Of more practical interest, perhaps, is the question of whether or not the absolute rating scale for aircraft noise is unique and applies only to aircraft. Although British studies indicate that rating scales for aircraft noise and noise from motor vehicles are similar at low or moderate levels, they diverge significantly at moderate

and high levels. These results, however, are based upon tests using generally different subjects for the different judgment tests and different absolute rating scales. It would therefore seem desirable to extend exploration of absolute noise rating judgments to include other types of noises, particularly motor vehicle noise, to better determine the range over which an unique scale of aircraft noise judgments can be applied.

REFERENCES

1. K. D. Kryter "Scaling Human Reactions to the Sound from Aircraft" - J. Acoust. Soc. Am., 31 1415-1429, (1959).

2. K. D. Kryter, K. S. Pearsons "Judgement Tests of the Sound from Piston, Turbojet and Turbofan Aircraft", Sound, 1, 24-31 (Mar.-Apr. 1962).

3. K. D. Kryter, K. S. Pearsons "Some Effects of Spectral Content and Duration on Perceived Noise Level" - J. Acoust. Soc. Am., 35, 866-883 (1963).

4. K. D. Kryter "The Meaning and Measurement of Perceived Noise Level", Noise Control, 6, 12-27 (Sept.-Oct. 1960).

5. D. W. Robinson, W. C. Copeland, A. J. Rennie "Motor Vehicle Noise Measurement", Engineer, 211, 493-497 (1961).

6. C. H. G. Mills, D. W. Robinson "The Subjective Rating of Motor Vehicle Noise", Appendix IX, Noise, Final Report, Committee on the Problem of Noise, July 1963, HMSO (London).

7. D. W. Robinson, J. M. Bowsher, W. C. Copeland "On Judging the Noise from Aircraft in Flight", Acustica, 13, 324-330 (1963).

8. Bolt, Beranek and Newman Tech. Report "Land Use Planning Relating to Aircraft Noise", published by FAA (Oct. 1964).

9. K. D. Kryter "Hearing Impairment for Speech" AMA Arch. Otolaryng, 77, 598-602 (1963).

10. E. L. Crow, F. A. Davis, M. W. Maxfield "Statistics Manual", Dover Publications, Inc., New York (1960).

11. W. J. Dixon, F. J. Massey, Jr. "Introduction to Statistical Analysis", McGraw-Hill Book Co., Inc. (1957), Chap. 7.

12. J. W. Little "Human Response to Jet Engine Noises", Noise Control, 7, 11-13 (1961).

13. "Social Survey in the vicinity of London (Heathrow) Airport", Appendix XI, Noise, Final Report, Committee on the Problem of Noise, July 1963, HMSO (London).

14. Bolt Beranek and Newman Inc., Technical Report "Land Use Planning Relating to Aircraft Noise", FAA (October 1964). Also published by Dept. of Defense as AFM 86-5, TM 5-365, NAVDOCKS P-98, "Land Use Planning with Respect to Aircraft Noise".

15. S. S. Stevens "The Measurement of Loudness", J. Acoust. Soc. Am., 27, 815-829 (1955).

16. S. S. Stevens "Calculation of the Loudness of Complex Noise", J. Acoust. Soc. Am., 28, 807-832 (1956).

17. D. E. Broadbent, D. W. Robinson "Subjective Measurements of the Relative Annoyance of Simulated Sonic Bangs and Aircraft Noise", J. Sound Vib., 1, 162-174 (1964).

APPENDIX A

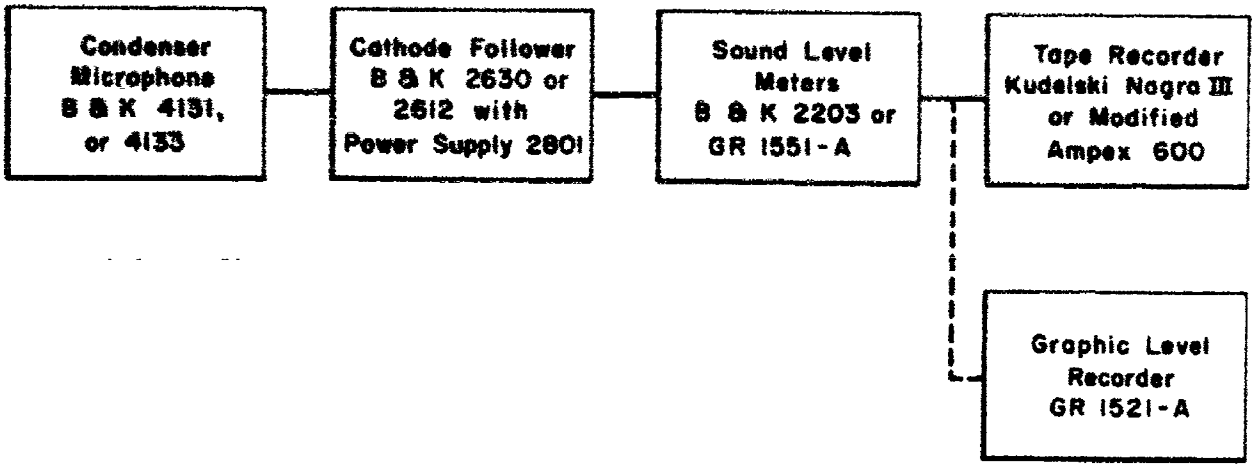
MEASUREMENT AND ANALYSIS OF FLYOVER NOISE

The aircraft noise signals were measured at single positions in the living room, bedroom and outdoors during the judgment tests. Outdoors and in the living room, the noise signals were recorded on magnetic tape for later analysis; in the bedroom, noise signals were either monitored directly with a sound level meter and a graphic level recorder or were recorded on tape. Figure A-1 shows the data recording and data analysis systems.

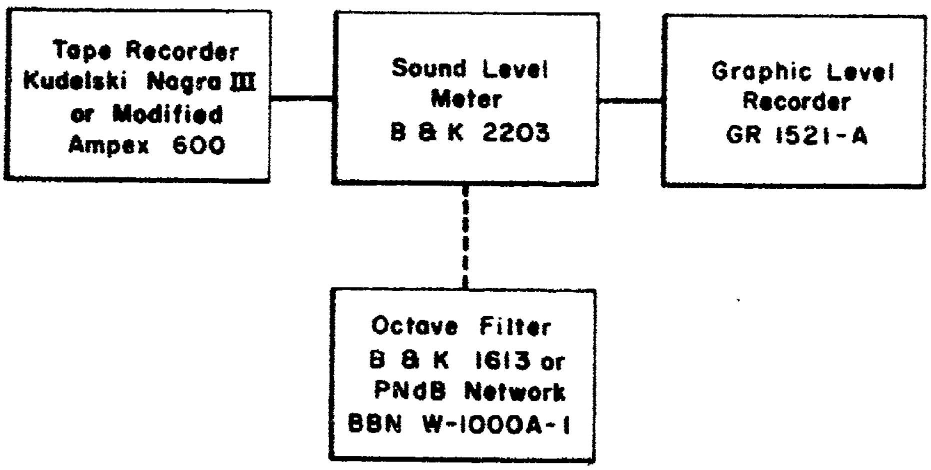
In addition to flyovers during the test session, a number of flyovers were recorded indoors in the two test buildings to determine the variation in noise levels at the subject seat positions in the living room and bedrooms. For these seat calibration measurements, noise from aircraft flyovers was recorded simultaneously at the room monitoring position and at successive seat positions throughout the room. This seat calibration procedure was repeated in the living room using the recorded flyover signal of tests 1 and 3 as the test signal instead of actual flyovers.

All of the noise signals were first analyzed by passing the signal through a fixed frequency weighting network, the dBA scale of the sound level meter. In addition, for approximately 25% of the recorded flyovers, the maximum flyover levels in octave frequency bands were determined. From comparison of the perceived noise levels calculated from the octave band measurements and the corresponding dBA values, correction values were obtained relating dBA values to calculated perceived noise levels. These values were then applied to the remaining dBA values to obtain estimates of the perceived noise levels.

The basis for this procedure rests upon previous studies at BBN and elsewhere,2,4,7/ which show that perceived noise



A. DATA RECORDING SYSTEM



B. DATA ANALYSIS SYSTEM

FIGURE A-1. FLYOVER NOISE RECORDING AND ANALYSIS SYSTEM

levels can be estimated with errors which are small compared with the dispersion expected from the subjective judgment test results, by use of a frequency-weighting network, such as the dBA scale network of a sound level meter or a perceived noise level (PNL) network (which approximates the 40-noy equal noisiness contour).

An earlier analysis of flyover noise recorded in the vicinity of Los Angeles International Airport had shown no significant difference in the accuracy of estimation afforded by the dBA or the PNL networks. On the basis of these earlier results, the dBA network was selected to process most of the flyover data because of convenience since it is incorporated as an internal network in the sound level meters.

Table A-I shows the differences (and standard deviations for the differences) between perceived noise levels calculated from the octave band data and the dBA and PNL network values. Figure A-2 shows the relative frequency response of the two weighting networks.

Consistent with the earlier analysis the standard deviations, shown in Table A-I, also show little difference between dBA and PNL network variations except for the case of approach flyovers measured indoors. In this case the PNL network levels yield smaller standard deviations. In any event, the standard deviations indicated in Table A-I for either the dBA network or the PNL network are much smaller than the dispersion in the subjective test responses. Thus, this method of estimating perceived noise levels should not contribute appreciably to the dispersion observed for the test results.

The average differences between perceived noise levels calculated from octave band data and the dBA values can be compared with those observed in previous studies. Table A-II shows the average difference between calculated perceived noise levels and dBA values for the present measurement, those measured earlier at Los Angeles International Airport and those reported by Robinson and

TABLE A-I

COMPARISON OF DIFFERENCES

BETWEEN CALCULATED PERCEIVED NOISE LEVELS

AND dBA AND PNL NETWORK VALUES

Type of Noise Signal	Measurement Location	Analysis Network	Turbojet and Turbofan Aircraft			Propeller Aircraft		
			No. of Meas.	Mean	Std.Dev.	No.of Meas.	Mean	Std.Dev.
Takeoff	Outside	dBA	27	11.6	1.3	3	13.5	-
		PNL	26	32.0*	1.2	-	-	-
	Inside	dBA	45	12.4	1.5	10	14.2	2.0
		PNL	23	33.9*	1.4	-	-	-
Approach	Outside	dBA	42	12.4	1.7	22	13.3	2.0
		PNL	42	32.8*	1.7	-	-	-
	Inside	dBA	55	13.6	1.8	28	12.9	1.3
		PNL	37	32.1*	0.9	-	-	-

* Includes electrical insertion loss of W1000 A-1 network. This loss is 25 dB at 800 cps; the insertion loss at other frequencies is given by addition of 25 dB to the relative loss values of Figure A-2.

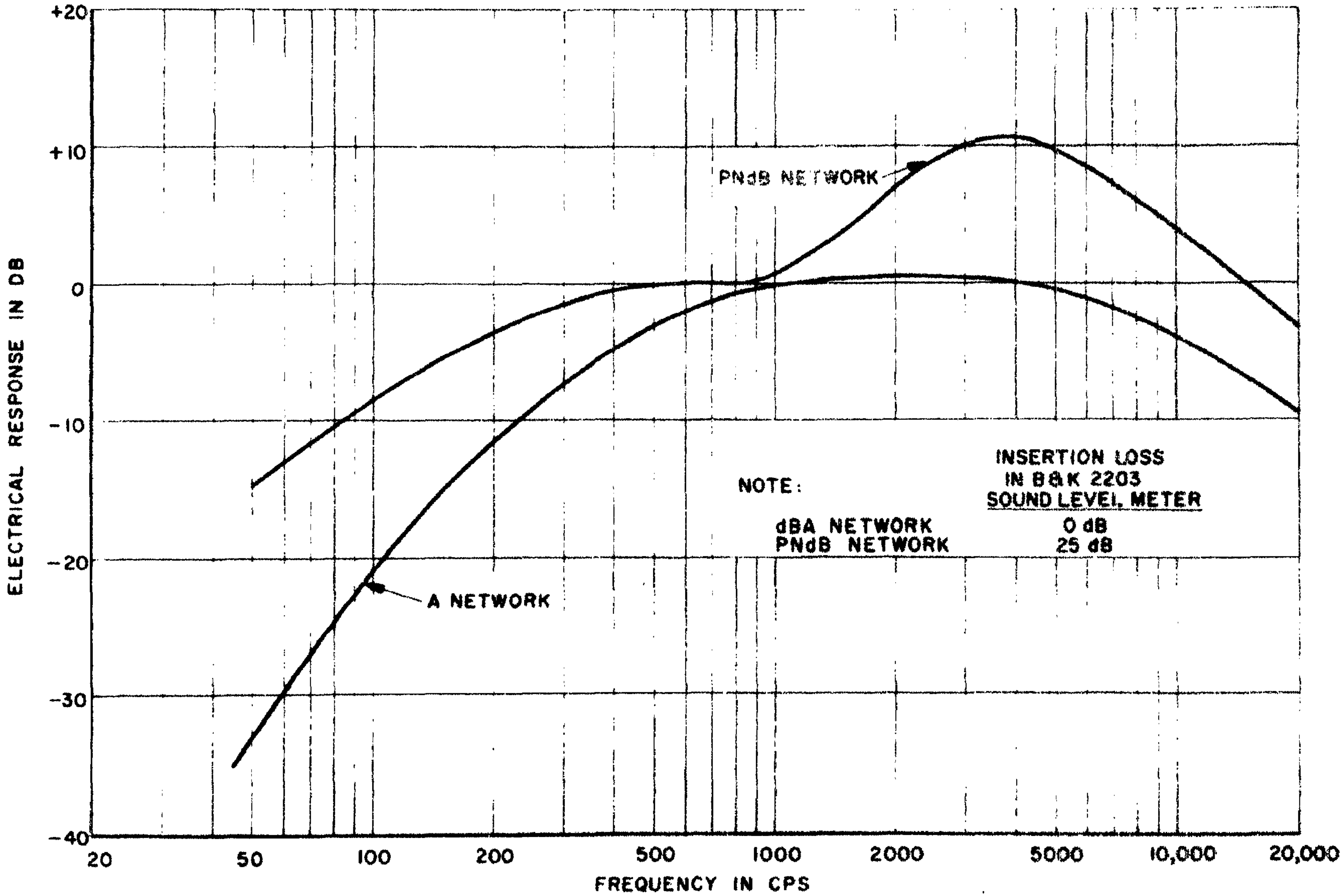


FIGURE A-2. RELATIVE FREQUENCY RESPONSE OF THE dBA AND PNdB WEIGHTING NETWORKS

TABLE A-II

COMPARISON OF AVERAGE DIFFERENCES

BETWEEN CALCULATED PERCEIVED NOISE LEVELS

AND dBA VALUES

Type of Noise Signal	Type of Aircraft	$PNdB_c$ - dBA				Total Spread dB
		LAIA March '64	LAIA Nov.-Dec.'63	Robinson 1,2/	Fleming 1,2/	
Takeoff	Turbojet and Turbofan	11.6	13.1	12.3	11.9	1.5
	Propeller	13.5	13.8	14.3	14.2	0.8
Approach	Turbojet and Turbofan	12.4	12.1	12.1	15.3	3.2
	Propeller	13.3	12.6	16.0	14.7	3.4

1 - From ref. (7)

2 - It is not known if data included turbofan aircraft flyovers nor if the propeller aircraft flyovers included both piston and turbine powered aircraft.

Fleming in England.7/ Both sets of flyover data at Los Angeles International Airport are based upon the current method for calculating PNdB3/; presumably the Robinson and Fleming values were calculated using PNdB calculation tables now superseded. Since, for jet aircraft, the current tables for calculating PNdB generally yield a lower perceived noise level for the same octave band spectra, the differences reported by Robinson or Fleming should be somewhat smaller if based upon the current PNdB calculation tables. Such an adjustment would bring their data into closer agreement with the Los Angeles International Airport measurements.

It should be pointed out that a portion of the differences between calculated perceived noise level and measured network values (either dBA or PNL networks) is dependent upon details of the data analysis procedure and of the instrumentation characteristics. For example, a change in the type of graphic level recorder used, which generally involves a change in the dynamic rectifying and writing characteristics of the instrument, may result in a measurable change in the differences between calculated perceived noise levels and network values.

From analysis of the seat calibration data, the maximum variation between seat positions and monitor positions was found to be ± 3 PNdB. The rms value of the standard deviations for the variations observed in the four test rooms was 1.2 PNdB. These values were observed without test subjects present. With subjects in the rooms, the variations in the room noise levels may have increased slightly.

APPENDIX B

SAMPLE TEST INSTRUCTIONS AND SCHEDULES

In this appendix are included copies of the background information questionnaire, general instructions, and Tests 1, 2, and 3 score sheets; this material was furnished to all subjects participating in the judgment tests. Also included is a copy of a test schedule covering two consecutive days (6 sessions) of testing. Separate test schedules were composed for each two days of testing.

BACKGROUND INFORMATION SHEET

Subject No. ____________ Sex ________________

Age Group (circle one) 20-29, 30-39, 40-49, 50 or more

Occupation ____

1) How many times per day are you normally aware of the noise of aircraft flyovers at your present residence?

   Less than once

   1-5 times

   6-10 times

   11-20 times

   21 or more times

2) How long have you lived at your present residence?

   ____

3) How many times per day were you normally aware of the noise of aircraft flyovers at a former residence? Consider only the residence with the largest number of flyovers per day.

   Less than once

   1-5 times

   6-10 times

   11-20 times

   21 or more times

4) When and for how long did you live at this former residence? ________________________________

5) Using the following scale please rate the average noise present at your home.

Quiet	Slightly Noisy	Moderately Noisy	Very Noisy	Extremely Noisy

6) Using the following scale please rate the average noise present at your place of employment.

Quiet	Slightly Noisy	Moderately Noisy	Very Noisy	Extremely Noisy

GENERAL INSTRUCTIONS

The purpose of conducting these tests is to learn more about subjective acceptability of aircraft flyovers. The tests are part of a program designed to obtain information that will be of aid in planning land use around airports.

You may smoke, study, read, write, converse during the test, but we ask that you do not discuss your answers among yourselves or in any way bias one another by comparing results. Try to make yourself at home. The tests will last approximately three hours. If you have any questions, please feel free to ask them.

Subject No. __________ Seat: m n o p q r s

Date __________ Location: Lennox El Segundo

Time __________ Living Room Bedroom Outdoors

INSTRUCTIONS FOR TEST 1

Prior to the following test you will hear a tape recordind of an aircraft flyover. Please assign the number 100 to it and mark it on your answer sheet in the space labeled "Recording." At some time later you will hear the sound of an actual aircraft flyover followed by the same recorded flyover to which you assigned a number. Your job is to assign a number to the actual flyover according to how noisy it is compared to the recording. Mark this number on your answer sheet at the space provided for each aircraft flyover. For example, if you felt the actual flyover was twice as noisy as the recorded flyover, you would place a 200 in the space provided. If on the other hand you felt the flyover was one-half as noisy as the recording, you would place a 50 in the space. For your judgment, consider the aircraft flyover would occur 20-30 times during the day and night.

Repeat this procedure for each aircraft flyover.

ANSWER SHEET FOR TEST 1

Recording __________

1 __________ 6 __________

2 __________ 7 __________

3 __________ 8 __________

4 __________ 9 __________

5 __________ 10 __________

Subject No. ____________ Seat: m n o p q r s

Date ________________ Location: Lennox El Segundo

Time ________________ Living Room Bedroom Outdoors

INSTRUCTIONS FOR TEST 2

During the following tests you will first hear an aircraft flying overhead. Please assign the number 100 to it and mark it in the space provided for aircraft flyover No. 1. Each subsequent flyover should be rated by assigning a number to each flyover according to how noisy it was compared to the first. Mark this number on your answer sheet in the space provided. For example, if you felt the actual flyover was twice as noisy, you would place a 200 in the space provided. If on the other hand you felt the flyover was one-half as noisy as the first, you would place a 50 in the space. For your judgment, consider the aircraft fly-overs would occur 20-30 times during the day and night.

Repeat this procedure for each aircraft flyover.

ANSWER SHEET FOR TEST 2

1 ____________ 6 ____________

2 ____________ 7 ____________

3 ____________ 8 ____________

4 ____________ 9 ____________

5 ____________ 10 ____________

Subject ____________ Seat: m n o p q r s

Date ____________ Location: Lennox El Segundo

Time ____________ Living Room Bedroom Outdoors

INSTRUCTIONS FOR TEST 3

During the following test, you will first hear an aircraft flying overhead. Your job is to rate the noise of the aircraft flyover on an acceptability scale. According to your rating, place a mark along the scale provided on the answer sheet for each aircraft flyover. Feel free to mark anywhere along the scale rather than just at the labeled points. The end points of the scale may be used for extreme cases. In making your judgment consider that the flyover would occur at your home 20-30 times during the day and night.

ANSWER SHEET FOR TEST 3

1) Of No Concern — Acceptable — Barely Acceptable — Unacceptable

2) Of No Concern — Acceptable — Barely Acceptable — Unacceptable

3) Of No Concern — Acceptable — Barely Acceptable — Unacceptable

4) Of No Concern — Acceptable — Barely Acceptable — Unacceptable

5) Of No Concern — Acceptable — Barely Acceptable — Unacceptable

6) Of No Concern — Acceptable — Barely Acceptable — Unacceptable

7) Of No Concern — Acceptable — Barely Acceptable — Unacceptable

8) Of No Concern — Acceptable — Barely Acceptable — Unacceptable

9) Of No Concern — Acceptable — Barely Acceptable — Unacceptable

10) Of No Concern — Acceptable — Barely Acceptable — Unacceptable

COPY OF A TEST SCHEDULE COVERING

TWO DAYS OF JUDGEMENT TESTS

Test Session	1			2		
Date	18 Mar 64			19 Mar 64		
Location	EL SEGUNDO			EL SEGUNDO		
Test Period	1	2	3	1	2	3
Group A	BR	O	LR	O	LR	BR
	3	3	1,3	2	1,3	2
B	BR	LR	BR	LR	O	O
	2	3,1	3	3,1	3	2
C	LR	LR	O	BR	O	BR
	1,3	3,1	3	2	2	3
D	LR	O	LR	BR	BR	O
	1,3	2	1,3	3	2	3
E	O	BR	O	LR	BR	LR
	3	2	2	3,1	3	3,1
F	O	BR	BR	O	LR	LR
	2	3	2	3	1,3	3,1

TEST SERIES II

APPENDIX C

SOURCES OF VARIABILITY IN CATEGORY JUDGMENTS OF AIRCRAFT NOISE ACCEPTABILITY

The dispersion found in the data for Test 3 arises from a number of sources. Probably the four chief sources of variability are:

1) Errors in objective measurement arising from instrumentation, calibration and data analysis errors, and variations in the noise environment at the individual subject positions.

2) Lack of correspondence between the objective measure of noise (perceived noise level) and subjective measures of noise acceptability.

3) Variability among different observers in their judgment of the noise.

4) Lack of consistency or repeatability in the observers' judgments.

If we assume that the total test variance (square of the test standard deviation) is equal to the sum of the variances introduced by each source of dispersion, we can obtain estimates of the size of each source.

Objective measurement error is probably the smallest of the four sources of variability. A value of 2 PNdB can be assigned as a likely measure of the standard deviation for this source. This value of 2 PNdB is based upon consideration of errors arising from differences between noise levels at monitor and seat positions, and errors due to the method of calculating the perceived noise level from objective measurements. Standard deviation values for both these sources of variability are given in Appendix A, where a value of 1.2 PNdB is estimated for the standard deviation measuring the variability in levels

between seat and monitor positions, and a value of 1.7 PNdB for the error in calculating PNdB from the objective noise measurements. Assuming an average slope of 0.20 for the curves relating acceptability ratings to perceived noise levels, the standard deviation for this source of variability is 0.4 in acceptability rating units.

An estimate of the variability contributed by the lack of consistency in individual observers' judgments is provided by study of Test 3 judgments in the living room where observers listened to recorded flyovers. These tests were the only tests in which there was replication. Each subject judged the same stimulus during two different test sessions (occurring on the same or a different day of testing) and, perhaps, at different positions in the room.

Analysis of the changes in individual subject scores when rating the same noise signal yields a pooled estimate for the standard deviation of 1.03 units for combined takeoff and approach judgments. (There was little difference in standard deviation values for approach and takeoff judgments; pooled estimate values of the standard deviation of 1.06 and 1.00 units were calculated for the separate sets of approach and takeoff judgments.) Assuming that this pooled estimate of the standard deviation results only from objective measurement error and lack of consistency in individual subject judgments, a standard deviation of 0.95 (4.8 PNdB) is calculated as a measure of variability due solely to lack of consistency in subject judgments.

An estimate of the variability due to variations in judgments among subjects can be obtained by study of subject scores when listening to the same flyover noise signal. Pooled estimates of the standard deviation for subject scores when listening to the same flyover signal varied from 1.10 units to 1.43 units for the six different tests. The pooled estimate of the standard deviation for the combined tests was 1.29 units (6.5 PNdB). This value may be considered to be a measure of dispersion resulting from lack of consistency in individual subject judgments and measurement error, as

well as variability among subjects. Assigning previously estimated values for the former two sources of variability, an estimate of the standard deviation due to variability among subjects of approximately 0.87 units (4.4 PNdB) is obtained. This standard deviation is nearly as large as that estimated for the lack of consistency in individual subject judgments.

The pooled estimate of the standard deviation of 1.29 units (6.5 PNdB), arising from differences in subject scores when listening to the same flyover signal can be compared with one of the values reported from the Farnborough judgment tests. (Differences in the rating scales for the Farnborough and Los Angeles tests permit only a rough comparison to be made.) For the second day of testing at Farnborough in which flyovers were judged outdoors on a "noisiness" rating scale, the standard deviation for scores of listeners rating the same noise signal was 1.1 unit on the "noisiness" rating scale. This standard deviation amounts to approximately 8.5 PNdB when evaluated using the midscale slope of the curve relating the subjective noisiness judgments and noise level.*

The estimate of variability due to differences among subjects, together with the estimates for measurement error and lack of consistency, may now be used to estimate the variability due to lack of correspondence between objective measurement scales and subjective rating scales. Such an estimate can be obtained by assuming that the standard deviation for judgment scores at specific levels of noise results from all four sources of variability. Thus, from the pooled estimate value of the standard deviation for judgment scores at specific noise levels, 1.55, and the estimates just obtained for three sources of variability, one obtains an estimate of 0.85 units (4.3 PNdB) for the standard deviation due to lack of

---

* See Fig. 2, Ref. 7

correspondence between objective scales and subjective scales. This estimate is less than the estimated standard deviations for subject variability and individual subject consistency.

The standard deviation values for each major source of variability, determined as discussed above, are tabulated in Table III in the body of the report.

FINAL REPORT

Contract No. FA-WA-4409

SRDS Report No. RD-65-130

Project 430-001-01R

PART III

AN ANALYSIS OF SOME FACTORS AFFECTING COMMUNITY-AIRPORT DECISION-MAKING

December 1965

Prepared By

Fremont J. Lyden

BOLT BERANEK AND NEWMAN INC.
15808 Wyandotte Street
Van Nuys, California 91406

ABSTRACT

Results of the application of a decision-flow methodology to seventeen case histories of community decision-making are reported. Five of the cases deal directly with airport-community decisions, four with land use and the remainder with major spheres of governmental decision-making in metropolitan areas. Under the hypothesis that the reaching of a public decision (i.e., construction of a new airport, location of an expressway) can be identified in terms of specific events, or subdecisions, which can be analytically classified and placed in a time relationship to one another, each case history was divided into a number of subdecisions.

Each subdecision was analyzed in terms of a stimulus (reason for the event), response (identifiable action), and consequences, which usually provided the stimulus for the succeeding subdecision. Initiators of actions and other participants in each subdecision (individual actors and groups) were identified and classified as well as were the major inputs of information used to arrive at a subdecision (legal criteria, budgetary policy, administrative policy, technical standards). Subdecisions, classified in sequential order, were segregated into quarters.

Some clear patterns of behavior emerge from the case findings permitting the development of a number of hypotheses for empirical validation. The airport cases follow the same general patterns as observed for the other cases investigated.

The hypotheses suggest strongly that the governmental administrative agencies dominate the decision process. For example, most actions are initiated in a governmental setting. The largest proportion of initiators and participants in action are governmental personnel, and the primary actor is usually a chief executive or departmental head. It appears evident that the administrator is most frequently the coordinator of activity effort making it important for him to know which types of groups and individuals play what kinds of roles at the different points of the decision process.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

AN ANALYSIS OF SOME FACTORS AFFECTING COMMUNITY-AIRPORT DECISION-MAKING

PREFACE

This report was written by Professor Fremont J. Lyden, Assistant Professor of the Graduate School of Public Affairs, University of Washington, acting as a consultant to Bolt Beranek and Newman, Inc. (BBN). Other consultants to BBN who participated with Professor Lyden in various phases of the studies were Dr. Robert Warren, and Messrs. Jack Fuller and Harold McCurty, also of the University of Washington.

Task No. 3 of the project work statement calls for an "Analysis of overt action and community action potential." This study area encompasses investigation of some of the complex relationships between communities and airports. Some of the reasons for investigating such relationships are discussed and diagramed in Part I of FAA Report No. RD-64-148*. As pointed out in that report, our understanding of the complex linkages between the psychological response of individuals to aircraft noise and possible community actions to control, limit or modify airport and aircraft operations is incomplete and fragmentary. In the belief that the application of modern techniques for investigating sociological and public administration problems might yield new understanding of pertinent linkages between communities and airports, BBN asked Professor Lyden to explore problems of community decision-making with reference to airport and aircraft noise problems.

---

* BBN Report No. 1093 "Analysis of Community and Airport Relationships/Noise Abatement - Technical Report; Work Accomplishments, May 1963 through April 1964" (December 1964).

I. INTRODUCTION

The studies summarized in this report consisted of the design and test of a middle-range decision-flow methodology. Findings elicited from application of the decision-flow methodology to 17 case studies are described in the body of the report. Published case studies were relied upon for data and decisions other than those specifically involving airport-community relations were included to provide a sufficient amount of data for statistical analysis. Bearing these shortcomings in mind, the hypotheses suggested by these findings should provide the basis for field research which can, in turn, be used to assist airport authorities in their job of policy coordination.

Some comment should also be made about what research has been undertaken for analyzing community responses which are not interpreted or are inadequately interpreted in the context of the decision process. Public opinion studies, for example, have frequently been conducted to elicit community attitudes toward the airport noise problem. Can the opinions thus elicited be related to overt behavior patterns? In the Fall 1964 issue of the <u>Public Opinion Quarterly</u>, Professor Leon Festinger raises the question of the relation of attitudes to subsequent behavior ("Behavioral Support for Opinion Change," pp. 403-417). After surveying the field, he concludes that few research attempts have been made to study this relationship and the investigations which have been conducted have yielded inconclusive results.

Studies of community responses have been conducted under varied circumstances by researchers with diverse interests and backgrounds. Well over 100 studies of community response to disaster have been undertaken. The results of these studies are catalogued and interpreted in

Preceding Page Blank

George W. Baker and Dwight W. Chapman's Man and Society in Disaster (New York: Basic Books, 1962). Community reactions to highway location and relocation work has also received a considerable amount of study. Floyd Thiel's article in the April 1962 issue of Public Roads ("Social Effects of Modern Highway Transportation," pp. 1-10) provides a good summary of many such efforts. Also Richard Zettel and Paul Shuldiner's Freeway Location Conflicts in California (Berkeley: Institute of Transportation and Traffic Engineering, Research Report No. 29, University of California, January 1959) has a number of case histories summarized in capsule form.

The likelihood of the public acting when faced by threats of injury in persons or damage to property is investigated by Robert Kates in six potential flood areas in Hazard and Choice Perception in Flood Plain Management (Chicago: Department of Geography, University of Chicago, 1962).

All of these studies have some relevance to the problem of community-airport relationships, but none of them raise strictly identical problems. Furthermore, the findings extracted from other studies yield conclusions which are hardly definite enough to be used for predictive purposes. Quite the contrary, in most instances they point up how little we know about community response patterns.

It was for this reason that the decision-making approach was applied in the studies we undertook. The decision process is the focal point around which most community needs are satisfied when governmental action is required. Although not all community responses are immediately reflected by actions occurring in the decision process, if the need is critical enough and of sufficient permanence to merit governmental attention, some actors or groups -- governmental or nongovernmental -- will introduce it into the decision process. The question of who will do this, when and in the context of what organizational setting is what the airport authorities need to know if they are

to recognize potential conflict and undertake efforts to alleviate it. The methodologies proposed in this report were designed to provide them with such information.

The next section of the report outlines the approach employed in the analysis of the case studies. The analysis findings are discussed in detail in Section III. Section IV summarizes the conclusions of the study. A Glossary is provided at the end of the report which defines some of the terminology used in the report.

II. DECISION-MAKING ANALYSIS APPROACH

A. Statement of Problem

This investigation is directed toward the development of a methodology for studying the decision-making process involved in airport-community relationships. Decisions are usually identified by some rather specific activity effort. We may speak of the airport's decision to extend its runway, to build a parking lot, to raise its landing fees, to purchase property for runway clear zones, etc. Yet such decisions are not made by a particular individual or group of individuals at a specific point in time. Decisions rather emerge out of a process in which a variety of governmental and non-governmental participants communicate facts, ideas, and points of view over time. There are certain events which can be identified in this process which either facilitate or deter the arrival at an eventual decision. In trying to characterize how decisions are made, however, we frequently telescope this stream of events into a generalization about behavior or we give undue importance to only a few of the events which we assume to be of most importance. In either event, our description of the decision-making process is so permeated by subjective interpretation that its relation to reality is highly dubious.

What we need, then, is a methodological approach for studying decision-making which will allow us to give due consideration to all activity-effort involved in reaching the decision and to minimize the effect of subjective interpretation.

It is the object of this study to attempt to validate a "decision-flow" approach to the study of community-airport decision-making and to draw hypotheses which will enable airport decision-makers to work more effectively with the community in the arrival at mutually acceptable decisions.

B. Decision-Flow Methodology

It is hypothesized that it is possible to identify specific events or subdecisions involved in the reaching of a public decision and that each of these subdecisions can be analy-

tically classified and placed in a time relationship to each other.

The analytic scheme for classifying subdecisions is based on the assumption that for each there will be:

(1) a stimulus, or reason for the event to occur

(2) a response, the identifiable Action which takes place (a meeting is held, a vote is taken, a legal complaint is filed, etc.) and

(3) a Consequence, which will usually provide the stimulus for the succeeding subdecision in the decision process.

In addition, it will be possible to identify the initiators of Actions and other participants in each subdecision by their governmental or non-governmental group affiliation. Where "groups" rather than their representatives participate in subdecisions, it should be possible to classify the type of groups involved. Finally, where major inputs of information are used in arriving at a subdecision (e.g., legal criteria, budgetary policy, administrative policy, technical standards, etc.), they should be identifiable. The proposed classification of: Actions, Consequences, Actor Affiliations, Organizational Groups, and Inputs is set forth in Appendix A.

Using the above classification, all subdecisions identifiable in each of the 17 community public policy decisions to be studied (discussed in next section) were classified in sequential order. Two graduate student analysts read and classified each case to insure uniform application of the classification. An illustration of how decision-flows were actually constructed is given in Appendix B. The total number of subdecisions in each case were then segregated into those constituting the first 25%, the second 25%, the third 25%, and the fourth 25% of the subdecisions. Hereafter in this report subdecisions will be referred to as occurring in the first, second, third, or fourth quarter of the decision.

The time span encompassed by a decision-flow varied from

several weeks in some cases to several months or years in other cases. The division of decision-flows into quarters is justified on an analytic rather than on an absolute time dimension basis. It is assumed that a number of different types of Actions occurring in some sequential relationship to each other are involved in problem solution regardless of the total time which elapses in the decision-flow. By dividing each decision-flow into quarters, each including an equal number of subdecisions, it is possible to identify which types of Actions occur in the early, middle and late stages of the problem-solving process. From this analytic perspective, then, the question of the amount of time which actually elapses in any given decision-flow or in any quarter of a decision-flow is not particularly relevant. This is not to imply that time is ignored but rather that it is considered as a relative rather than an absolute characteristic of the decision process. In this respect, its significance is apparent in recorded Consequences which reflect delays, blockages, etc. in the decision process.

All subdecision data thus classified for the 17 case histories were coded and stored for computer sorting. Computer sorts were then made of all subdecisions by:

(1) Actions

(2) Consequences

(3) Organizational Groups

(4) Actors by Affiliation

(5) Contingency relationships between

- (a) Actions and Consequences
- (b) Actions and Organizational Groups
- (c) Actions and Actor Affiliation
- (d) Actions and Inputs
- (e) Consequences and Organizational Groups

(f) Consequences and Actor Affiliation

(g) Consequences and Inputs.

Each of these forms of tabulated data was then broken down according to whether they appeared in subdecisions in the first, second, third, or fourth quarter of the decision.

Finally, all of the above forms of tabulations were made for cases grouped according to the functional classification discussed below.

C. Sources of Data

The source of data for testing this methodology was 17 case studies of public policy decisions which were available in the published literature. Titles of these cases with their publication sources are listed in Table I. The number of subdecisions in each case is also listed in the table. Since our interest was in airport-community decisions (and more specifically those involving noise problems), we would have preferred to select cases dealing with this subject area. A sufficient number of cases, however, has not been published on this subject to provide adequate data for comparative analysis. Furthermore, studies which have been conducted on community decision-making indicate that a rather well established pattern of interrelationships exists among participants in each functional area of governmental concern. Although the specific actors involved in a municipal sewer problem may be different from those dominant in a public parks or a municipal airport problem, an established pattern of decision-making appears to exist in each. Since an insufficient number of cases was available in respect to airport management, we therefore selected a sampling of cases dealing with major areas of governmental decision-making in metropolitan areas. A random selection of cases could not even be made on this basis, though, in view of the limited number of cases available. A purposeful selection of 17 cases was therefore made on the basis that (1) each should deal with a governmental problem in a metropolitan setting, (2) each should present a sufficiently detailed narrative of the decision that the decision-flow methodology could be employed, and (3) a representative selection of long and short cases

TABLE I

CASE STUDIES USED IN DECISION-FLOW STUDY

	Case Title	Source	No. of Subdecisions
1.	"The Closing of Newark Airport"	Inter-University Case Program No. 27, University of Alabama Press, University of Alabama	67
2.	"Jets for the Great Swamp?"	Frost, Richard T. (ed.), Cases in State and Local Government (Englewood Cliffs: Prentice-Hall, 1961)	24
3.	"Detroit's Metropolitan Airport: The Fourteen-year Struggle over an Airport Site"	Mowitz, Robert J. and Deil Wright, Profile of a Metropolis (Detroit: Wayne State Universit, Press, 1962)	117
4.	"Gotham in the Air Age"	Stein, Harold (ed.), Public Administration and Policy Development (New York: Harcourt, Brace, 1952)	84
5.	"The Broome County Airport"	Frost, op cit	32
6.	"The Extension of the Lodge Expressway: Expressway Strategy in Motor City"	Mowitz and Wright, op cit	46
7.	"Moses on the Green"	Inter-University Case Program, No. 45, op cit	25
8.	"The County Buys Dunwoodie Golf Course"	Ibid., No. 61	29
9.	"Defending the Hill against Metal Houses"	Ibid., No. 26	24
10.	"South West Hyde Park: A Case of Failure to Achieve Popular Consensus"	Rossi, Peter and Robert Dentler, The Politics of Urban Renewal (New York: Free Press, 1961)	28
11.	"The Branch Hospital"	Banfield, Edward C., Political Influence (New York: Free Press, 1961)	13
12.	"The Welfare Merger"	Ibid.,	31
13.	"The Trenton Milk Contract"	Inter-University Case Program, No. 50 op cit	33
14.	"Water for Wauwatosa"	Frost, op cit	23
15.	"The Metropolitan Sewage Treatment Plant"	Martin, Roscoe, et al, Decisions in Syracuse (Bloomington: Indiana Univ. Press, 1961)	59
16.	"The Lonesome Train in Levittown"	Inter-University Case Program, No. 39 op cit	38
17.	"The Annexation Episode"	Janowitz, Morris (ed.), Community Political Systems (New York: Free Press, 1961)	8

(as measured by number of subdecisions) should be represented. After a canvass had been made of all relevant published cases, seventeen were chosen as follows:

No. of Cases	Functional Area	No. of Sub-decisions	No. of actors and groups
2	Airport operation	91	239
4	Transportation (Airport and Highway location)	279	652
4	Land Use	106	313
3	Health and Welfare	67	160
2	Utilities	82	196
2	Other (Jurisdiction, Schools)	46	113
	Totals	671	1673

Five of the cases deal directly with airport-community decisions (2 operation, 3 construction), four deal with land use (a functional government area of direct relevance to airport management), and the remainder represent major spheres of governmental decision-making in a metropolitan area.

III. CASE STUDY FINDINGS

The findings of this study can be presented in terms of five questions:

(1) What types of Actions are involved in the decision-making process?

(2) What Consequences ensue from Actions taken?

(3) What Inputs are associated with different types of Actions and Consequences?

(4) Who are the dominant Actors?

(5) In how many cases were legal actions taken to obstruct the decision-making process and how frequently were they successful?

Each of these five questions are discussed in the following subsections.

A. Types of Actions

All actions were classified as occurring either in a governmental or non-governmental setting - that is, they occurred in the framework of either a governmental or non-governmental organization (e.g., a complaint directed to a governmental official is conducted in a governmental setting, while one directed to an officer of the chamber of commerce is conducted in a non-governmental setting; a public hearing called by a government agency is conducted in a governmental setting while one called by the Better Roads Association is conducted in a non-governmental setting, etc.). Of the 671 subdecisions involved in the 17 cases studied, 71% occurred in a governmental setting, 27% in a non-governmental setting, and 2% were not classifiable.

Most of the subdecisions, approximately 80%, could be identified as essentially discrete contributions to the decision-making process. Although quite a variety of different types of Actions were encompassed in these subdecisions, all appear to fall into two broad categories of Action: (1) information and/or support seeking (e.g., request information, call

hearing, initiate contacts with the public or other governmental agency, establish decision-making mechanism, etc.), and (2) statement of policy position (e.g., prepare report, issuance of report, make public statement, etc.). In the 532 subdecisions so classified, the following types of Actions were found:

	Percent of Actions	
Subdecision Setting	Information and/ or Support Seeking	Statement of Policy Position
Government, administrative (263)	80	20
Government, legislative (110)	61	39
Non-governmental (159)	66	34

The fact that a high percent of actions associated with statements of policy position fell in the legislative setting is understandable since the legislature legitimatizes most governmental commitments. It is interesting to note, however, how high a percent of non-governmental subdecisions were involved in policy statement. It is obvious from the evidence that the great majority of the information and support seeking Actions related to gaining agreement fell into the governmental administrative setting.

These types of Action did not occur evenly over the duration of the cases studied. Since subdecisions were recorded in sequential order, it is possible to indicate what kinds of Actions occurred in the subdecisions coming in the first, second, third and fourth quarters of each case. This breakdown is shown in Table II.

Slightly over one-fourth of the government information-support seeking Actions in the government administrative setting occurred in each of the first two quarters of the decision process; while these activities dropped to 14% in the third quarter and rose again to 33% in the last quarter. The most intensive information-support activities

TABLE II

TIME DISTRIBUTION OF ACTIONS

Subdecision Setting and Type of Action	Percent of Actions occurring in each qtr. of decision process First	Second	Third	Fourth
Government, administrative				
Information-support seeking (211)	27	27	14	32
Statement-Policy Position (52)	24	27	25	25
Government, Legislature				
Information-support seeking (57)	19	26	37	19
Statement-Policy Position (43)	13	9	34	45
Non-governmental				
Information-support seeking (105)	24	37	26	15
Statement-Policy Position (54)	31	25	20	24

in the non-governmental setting occurred in the second quarter (37%) and the smallest percent of such activities in the last quarter (15%). Information support activities occurring in the governmental legislative setting increased through the first three quarters, reaching a peak in the third quarter (37%), and dropped off again in the last quarter (19%).

These data tell us that the administrative and non-governmental settings are about equally involved in information and support seeking Actions at the beginning of a decision. Then in the second quarter such Actions increase in the non-governmental setting, become more important in the legislative setting in the third quarter and in the administrative setting in the fourth quarter. The Actions occurring in the non-governmental setting therefore generate information and support seeking Actions in the legislative setting which in turn generate increased activity effort of this type in the administrative setting in the final quarter of the process.

Statements of policy position in non-governmental settings are made early in the case (31% in the first quarter and 25% in the second quarter), drop off a bit in the third quarter (20%) and increase again in the last quarter (24%). Policy statements in the legislative setting come primarily in the third (34%) and fourth (45%) quarters of the process; while in the administrative setting they are spread out about equally throughout the decision process. This means, then, that non-government activity efforts are concerned with policy statement early in the decision process, then increased activities are devoted to gaining information and support in the second quarter. This effort leads to increased Actions in the legislative setting in the third quarter, both in information-support seeking and policy declarations, and to legislative policy legitimatization in the last quarter.

As noted above, while some 80% of the subdecision actions could be classified as essentially discrete contributions to the decision-making process, the remainder dealt with such interlocking internalized procedures (such as motions, proposals, counterproposals, dissentions, etc. in a meeting) that they were classified separately. Those which represented (1) initiating action, (2) accepting actions under consideration and (3) rejecting or delaying such actions are

indicated in the following table according to the setting in which they occurred:

Subdecision Setting	Type of Action in Percent		
	Initiating	Accepting	Reject/ delay
Government deliberation (102)	30	56	14
Non-government deliberation (22)	54	14	32

Although the non-governmental subdecisions are too few in number to allow for any firm generalizations, it would appear that the internal deliberation process in the governmental and non-governmental settings is quite different. The governmental deliberation process is more stable, the non-governmental more dynamic and volatile. This finding is in agreement with the findings noted above that it is in the governmental (particularly administrative) setting where Actions involved with gaining information and support toward the reconciliation of differences are dominant; while the non-governmental setting is more closely related to Actions concerned with expressing community needs and reactions.

So far, we have identified governmental and non-governmental Actions in the decision process by the subdecision setting. Obviously, however, both governmental and non-governmental actors will be involved in subdecisions whether they occur in a governmental or non-governmental setting. Tables III and IV show the percent of actors (where specific actors are identifiable) and of organizational groups respectively which were involved in the subdecisions occurring in each quarter of the 17 cases under study.

Local government actors and agencies dominate the participation in subdecision actions. If federal and state are included, 70% of the actors and 58% of the organizations involved in subdecision Actions are governmental. Single purpose permanent organizations (e.g., pilot associations, real estate associations, state or local bar associations,

TABLE III

TIME DISTRIBUTION OF ACTOR PARTICIPATION IN ACTIONS

Actor Affiliation	Percent of Total	Percent Participating in Actions by Quarters: First	Second	Third	Fourth
Government					
Local (428)	54	24	25	29	22
Federal-State (130)	16	22	20	26	31
Non-Government					
Single purpose permanent (131)	17	24	29	27	20
Multiple purpose permanent (21)	3	14	10	48	29
Issue-created (17)	2	18	12	41	29
Unaffiliated (64)	8	31	34	27	8
	100				

TABLE IV

TIME DISTRIBUTION OF ORGANIZATIONAL GROUP PARTICIPATION IN ACTIONS

Organizational Group	Percent of Total	Percent Participating in Actions by Quarters: First	Second	Third	Fourth
Government					
Local (362)	41	24	23	28	25
Federal-State (152)	17	22	20	30	28
Non-Government					
Single purpose permanent (142)	16	28	19	30	23
Multiple purpose permanent (45)	5	20	20	27	33
Issue-created (116)	13	23	31	19	27
Clientele (61)	7	23	36	20	21
	100				

labor unions, etc.) dominate the non-governmental participation. Only 8% of the actor participation was by persons with no organizational affiliation, indicating the degree to which participation is carried on by recognized organized groups and their representatives.

Turning to the question of when different types of actors and groups participate in the decision process, it is apparent that local government actors and groups participate about equally throughout the process. State and federal actors and agencies show a slight increase in activity in the later stages of the decision.

Non-governmental actors affiliated with single purpose permanent groups peak in the second quarter (29%) with the types of groups they represent increasing their participation in the third quarter, apparently to provide institutional legitimatization for their representatives. Likewise, the non-governmental actors affiliated with multiple-purpose permanent groups (such as Chambers of Commerce, Leagues of Women Voters, Civic Associations, etc.) enter in the largest numbers in the third quarter (48%) followed by increased activity by multiple purpose groups in the last quarter (33%). Clientele groups (airlines in airport cases, contractors in urban renewal cases, etc.) served by the governmental organizations appear most frequently in the second quarter.

Unaffiliated actors appear most in the first two quarters; while the participation of issue-created groups is highest in the second quarter (31%), goes down in the third quarter (19%), and builds up (to 27%) again in the last quarter.

Figure 1 presents a graphic representation of the periods of greatest participation by actors and groups in the decision process.

The question of the proportion of governmental and non-governmental actors and groups participating in sub-decisions in government and non-governmental settings respectively has not yet been considered. (As will be recalled, the setting is the organizational context in which the Action takes place.) Tables V and VI present this information.

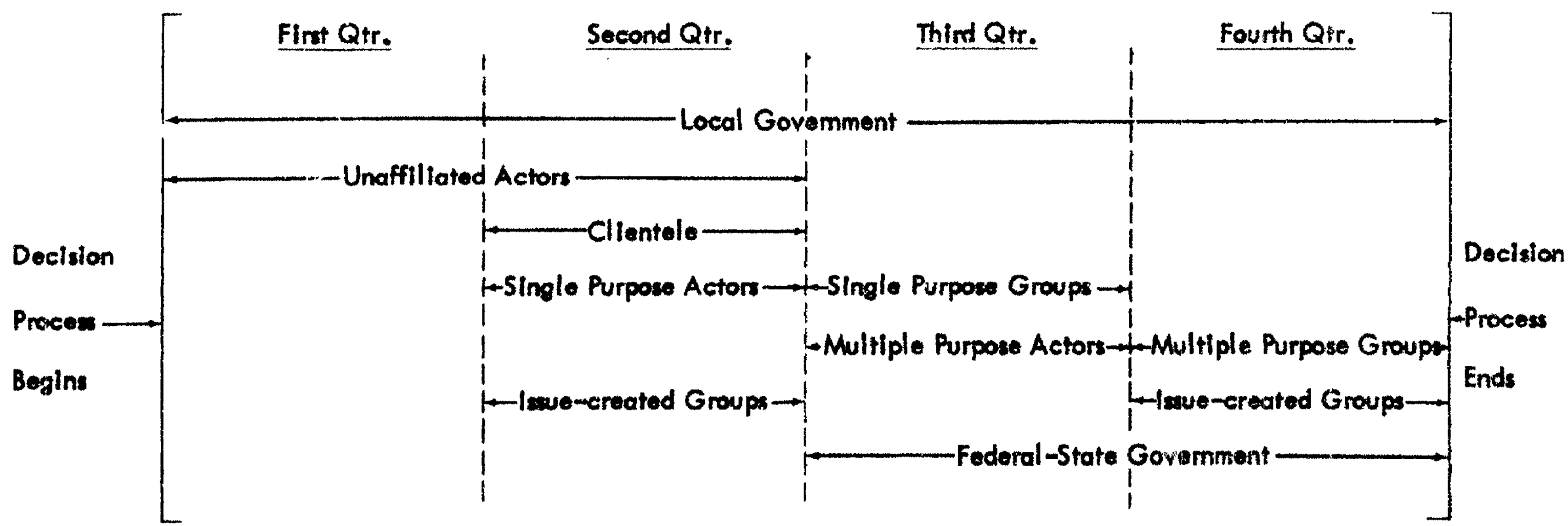


FIGURE 1. DECISION PROCESS CHART SHOWING PERIODS OF GREATEST ACTIVITY FOR ACTORS AND GROUPS
(Includes Government and Non-government Subdecisions)

TABLE V

GOVERNMENTAL AND NON-GOVERNMENTAL
ACTOR PARTICIPATION

Actor Affiliation	Percent of Actors by Subdecision Setting: Government (545)	Non-government (231)
Government		
Local	65	30
Federal-State	21	7
Non-government		
Single purpose permanent	9	36
Multiple purpose permanent	1	7
Issue-created	1	3
Unaffiliated	3	17
	100	100

TABLE VI

GOVERNMENTAL AND NON-GOVERNMENTAL
GROUP PARTICIPATION

Organizational Groups	Percent of Groups by Subdecision Setting: Government (475)	Non-government (181)
Government		
Local	50	21
Federal-State	23	6
Non-government		
Single purpose permanent	8	34
Multiple purpose permanent	2	12
Issue-created	10	21
Clientele	7	17
	100	100

As would be expected, the governmental and non-governmental actors and groups dominate the participation in their respective settings. Yet a significant overlap exists. Governmental actors constitute 37% of the actors and 27% of the groups in the non-governmental setting subdecisions; while non-governmental actors and groups constitute 14% and 27% of the actors and groups respectively in the governmental setting subdecisions. The question of where in the decision process such participation occurrs therefore becomes important in determining the relative roles played by government and non-governmental actors and groups respectively in each other's subdecision settings. Tables VII and VIII show such participation for actors by quarters.

TABLE VII

GOVERNMENT ACTOR PARTICIPATION
IN NON-GOVERNMENT SETTINGS

Actor Affiliation		Percent of Actor Participation by Quarters			
		First	Second	Third	Fourth
Local Government	(70)	43	21	19	17
Federal-State Government	(15)	40	27	20	13

TABLE VIII

NON-GOVERNMENT ACTOR PARTICIPATION
IN GOVERNMENT SETTINGS

Actor Affiliation		Percent of Actor Participation by Quarters			
		First	Second	Third	Fourth
Single Purpose permanent	(47)	15	23	28	34
Unaffiliated	(19)	16	21	40	21

Governmental actors participate most actively in non-governmental settings in the first quarter and take progressively less active part in such subdecisions in each succeeding quarter. The role played by governmental actors in these contexts is therefore primarily informational.

Participation in governmental settings by non-governmental actors affiliated with single purpose permanent groups builds up progressively from the first through the fourth quarter. Their participation takes on increased import, therefore, as the decision process unfolds. Unaffiliated actors also take increasing part in governmental subdecisions up through the third quarter after which such participation drops off. This behavior would indicate that while unaffiliated actors participate actively in problem definition, their interest wanes in the final problem resolution stage of the decision process.

Participation of governmental agencies, as contrasted with actors, in non-governmental subdecisions follows the same pattern as depicted for overall participation in Figure 1. The same is true for participation of non-governmental groups in governmental subdecisions.

Participation by actors and groups in government subdecision settings is depicted in Figure 2 by periods of greatest participation. From this chart it is evident that issue-created groups are brought into existence in the second quarter to determine and consolidate public opinion. Non-governmental groups and actors organize and develop strategy in a non-governmental context in the early stages of the decision process with governmental actors providing them with information. Unaffiliated actors move their point of reference from the non-governmental to the governmental setting in the third period. Finally, all organized groups come into their most active participation in the governmental subdecisions in the fourth quarter.

B. Types of Consequences

The second major question which must be considered is what consequences ensue from the Actions described in the preceding section. Although subdecision Consequences were more difficult to classify objectively than Actions, rigid

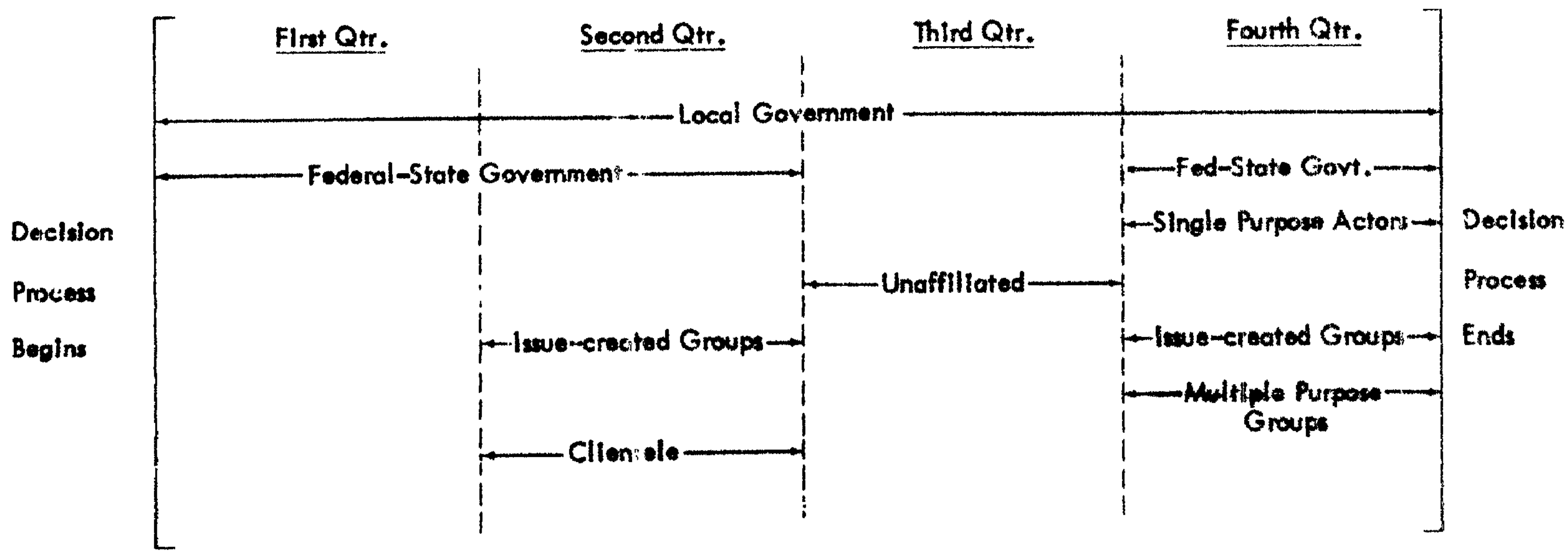


FIGURE 2. DECISION PROCESS CHART SHOWING PERIODS OF GREATEST ACTIVITY FOR ACTORS AND GROUPS IN GOVERNMENT SUBDECISIONS

adherence to the rule of evaluating subdecision Actions in terms of their effect on the ongoing flow of decision-making insured a reasonable degree of uniformity in classification. Consequences were identified as those which reflect: (1) the expression of needs to be met through the policy process, (2) the deterrence or delay of resolution in the policy process, (3) the resolution of differences in viewpoint or perspective, (4) generalized reactions by the public, and (5) generalized reactions by government.

The last two categories refer to consequences which indicate a generalized awareness of the problem, increased interest in the problem, decreased interest in the problem, etc. -- reactions which are nonspecific in character but do influence the ongoing decision process. The percent of each type of Consequences found in the 271 subdecisions studied and their distribution in each quarter of the decision process is given in Table IX.

TABLE IX

TIME DISTRIBUTION OF CONSEQUENCES

Type of Consequence	Percent of Total	Percent Appearing in each Quarter: First	Second	Third	Fourth
Expression of Needs (116)	17	33	22	21	23
Deterring Resolution (159)	24	20	18	34	28
Resolving Differences (53)	8	17	26	15	42
Public Reactions (116)	17	30	32	20	18
Government Reactions (210)	31	21	29	24	26
Other (17)	3				
	100				

The high proportion of Actions which result in deterring resolution (24%) indicates the importance of conflict situations in the decision process. The fact that such subdecisions occur more frequently in the last two quarters of the process may reflect the time lag involved in the public becoming aware of the problem, the time required for the coalescing of opposition activity-efforts, the increasing specificity of decision activity as the stage of commitment is approached, or some combination of these circumstances. Since public reactions and the expression of needs are noticeably apparent in the early stages of the process, it would appear that the increase of conflict occurring late in the process is not due primarily to any failure to communicate with the public at some earlier stage.

A consideration of Consequences by subdecision setting should shed further light on this situation. The proportion of each type of Consequence stemming out of subdecisions in the governmental and non-governmental settings respectively is shown in Table X.

TABLE X

DISTRIBUTION OF CONSEQUENCES
BY SUBDECISION SETTING

Type of Consequence	Percent of Consequences by Subdecision Setting		
	Government (475)	Non-Government (181)	Not Classifiable (15)
Expression of Needs	73	26	1
Deterring Resolution	68	30	2
Resolving Differences	98	2	--
Public Reaction	30	69	1
Government Reaction	86	10	4

Note that public reactions occur primarily as a result of Actions taken in the non-governmental setting. Actions involving the expression of needs and blocking Actions, resulting in the deterring of resolution, however, occur more frequently in the governmental setting. Finally, Actions concerned with the resolution of differences occur almost exclusively in the government setting. Thus, while initial public reactions are evidenced in non-governmental settings, most actors and groups enter into the governmental setting to facilitate or block Action, and almost all accommodation of differing points of view occurs in the governmental rather than in the non-governmental setting.

The question of timing now becomes appropriate to consider. Tables XI and XII delineate the proportion of Consequences stemming from governmental and non-governmental settings respectively in each quarter of the decision process.

In the course of the decision process, needs are expressed early in subdecisions in the non-governmental setting (43% in the first quarter and 30% in the second quarter). Public reactions stemming from subdecisions in the non-governmental setting occur primarily during the first three quarters with the largest proportion coming in the second quarter. Government reactions to non-governmental subdecision Actions occur predominantly in the first and fourth quarters.

When we turn to subdecisions occurring in the governmental setting, it will be observed that the expression of needs and public reactions are concentrated in the first and fourth quarters, Actions which deter the resolution of problems in the third quarter and the resolution of differences in the fourth quarter.

We can infer from these patterns of behavior that: (1) public needs are expressed early in the decision process in both the non-governmental and governmental settings but primarily in the former; (2) public reactions to governmental action occur in both settings early in the decision process, then move more into the non-governmental setting until the last quarter when they shift to the governmental setting; (3) actions involved in the deterrence of resolution occur quite uniformly throughout the

TABLE XI

TIME DISTRIBUTION OF CONSEQUENCES STEMMING FROM GOVERNMENTAL SETTINGS

Type of Consequence	Percent of Consequences Appearing in Each Quarter			
	First	Second	Third	Fourth
Expression of Needs (83)	29	19	24	28
Deterring Resolution (108)	19	16	37	28
Resolving Differences (52)	17	27	15	40
Public Reaction (35)	31	26	11	31
Government Reaction (180)	21	31	25	24

TABLE XII

TIME DISTRIBUTION OF CONSEQUENCES STEMMING FROM NON-GOVERNMENTAL SETTINGS

Type of Consequence	Percent of Consequences Appearing in Each Quarter			
	First	Second	Third	Fourth
Expression of Needs (30)	43	30	17	10
Deterring Resolution (48)	23	23	25	29
Resolving Differences (1)	--	--	--	--
Public Reactions (81)	26	32	27	15
Government Reactions (21)	33	19	14	33

process in the non-governmental setting but are concentrated in the third and fourth quarters in the governmental setting: (4) governmental reaction to subdecisions in the non-governmental setting are most pronounced early and late in the decision process; and (5) policy differences are resolved almost entirely in the governmental setting, primarily in the final quarter (40%) of the decision process.

In the previous section of this report, actors and groups were identified in terms of the stages in which they participated in the decision-making process and the types of subdecision Actions with which they were involved. It is logical, then, to consider at this point what consequences ensued from the Actions these actors and groups participated in. Tables XIII and XIV show this relationship for all major types of actors and groups.

As would be expected, the largest percent of local government and federal-state governmental actors and groups are associated with subdecision Actions resulting in governmental reactions. These represent the inter and intra governmental decision-making that constitutes such a large proportion of every decision process. Also a high proportion of these governmental actors and groups are involved in subdecision Actions which result in the deterring of resolution, a rather surprising finding in that such activity effort is commonly assumed to be associated primarily with non-governmental actors and groups.

The largest proportion of single purpose non-governmental actors are associated with Actions which have consequences of public reaction or the deterring of resolution. In contrast, a smaller proportion of these actors participated in actions concerned with resolving differences than any other type of actors. It will also be noted that almost 50% of the unaffiliated actors are associated with public reactions, although a sizeable number were also active in Actions which resulted in the deterrance of resolution.

Issue-created groups play an almost equal role in actions resulting in the deterring of resolution, public reaction, and governmental reaction. This pattern of participation reflects the multi-faceted communications role played by such groups. This is in marked contrast to the partici-

TABLE XIII

ACTOR PARTICIPATION AND TYPE OF CONSEQUENCE

Type of Consequence	Percent of Actors-by-Affiliation Related to Each Type of Consequence			
	Local Government (428)	Federal-State (129)	Single Purpose (131)	Unaffiliated (64)
Expression of Needs	18	21	24	14
Deterring Resolution	22	30	16	27
Resolving Differences	7	6	7	--
Public Reaction	14	2	31	47
Government Reaction	39	39	18	13
	100	100	100	100

TABLE XIV

GROUP PARTICIPATION AND TYPE OF CONSEQUENCE

Type of Consequence	Percent of Organized Groups Related to Each Type of Consequence					
	Local Government (362)	Federal State (152)	Issue Created (116)	Single Purpose (142)	Multiple Purpose (45)	Clientele (61)
Expression of Needs	16	24	16	13	11	21
Deterring Resolution	26	26	24	26	16	20
Resolving Differences	12	11	4	2	4	7
Public Reaction	12	7	27	34	52	15
Government Reaction	32	32	28	23	18	31
Other	2	--	1	2	--	6
	100	100	100	100	100	100

pation of the multiple purpose groups in Actions where the dominant Consequence was public reaction (52%).

Finally, a larger percentage of governmental actors and groups are involved in the resolution of differences than non-government groups. This is to be expected since legal legitimatization is accomplished in the governmental context. Of greater significance is the relative importance of clientele, issue-created and multiple purpose groups in comparison to single purpose groups in such accommodation type Actions.

In Figure 1, which was introduced in the previous subsection, actor and group participation was depicted graphically in terms of when in the decision process each type of actor and group was most active. It is now possible to add the dimension of subdecision Consequence to this visual presentation.

Figure 3 presents the same information contained in Figure 1 about actor and group participation and adds information on the most frequent Consequences associated with the types of subdecisions involved.

The most frequently occurring type of Consequence stemming from subdecisions engaged in by governmental actors and groups was government reaction-dialogue, carried on primarily in the governmental setting. The single exception to this generalization occurs in the local government participation in the third quarter when conflict type Consequences (deter resolution) predominated.

Clientele participation, occurring most frequently in the second quarter, was almost evenly spread among subdecisions having each of the various Consequences being considered. The whole procedure of becoming acquainted with the problem at hand, reacting, expressing needs, resorting to blocking or delay (where needs are given inadequate attention), and compromise are telescoped into the second quarter for such groups. This apparently is possible because of the ongoing communication between the governmental agencies and these clientele, res ing in each having a fairly clear idea of the other's perceptions and needs.

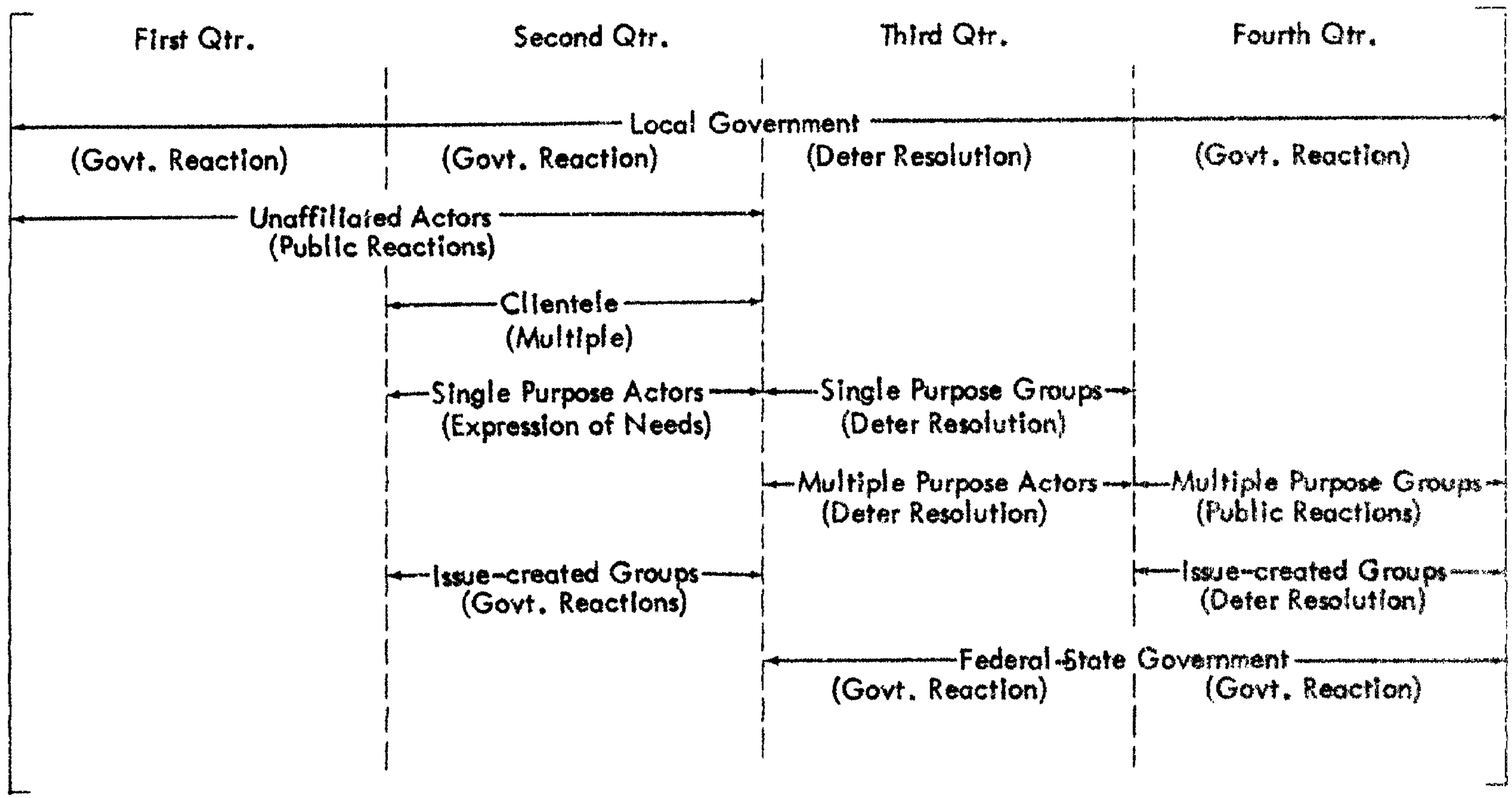


FIGURE 3. DECISION PROCESS CHART SHOWING PERIODS OF GREATEST ACTOR AND GROUP ACTIVITY IN RELATION TO SUBDECISION CONSEQUENCES

Actors affiliated with single purpose permanent groups most frequently participated in the second quarter in subdecisions reflecting the expression of needs. Such participation was followed by such actors becoming most active in the third quarter in subdecisions which deterred resolution.

Actors affiliated with multiple purpose permanent groups were also associated in the third quarter mostly with subdecisions which deterred resolution. This participation changes in the fourth quarter, however, when such groups become identified more with subdecisions associated with public reaction. Multiple purpose groups, then, become involved in many conflict-type subdecisions in the third quarter; but their participation in the final quarter was primarily associated with the communication of public attitudes.

In instances where issue-created organizations were used in the decision process, such groups were first most active in the second quarter in subdecisions which elicited governmental reactions. In such subdecision, then, the issue-created organization was apparently establishing its relationship to the governmental actors and agencies. In the fourth quarter, such groups again became quite active, but now in subdecisions which were associated with deterring resolution. Since most other actors and groups were involved in such subdecisions more frequently in the third quarter, it would appear that the issue-created group was being used to consolidate the basis for dissent in the final quarter.

Subdecisions resulting in compromise and legitimization (resolving differences) occurred primarily in the last quarter and were dominated by governmental actors and groups.

C. Subdecision Inputs

The types of information inputs used to decide upon what Actions to take at the subdecision level can also have important influences on the decision process. For example, where legal authority is used as the basis for taking an Action when the real issue involved is one of technical

feasibility, responses may also be made in terms of the legal dialogue instead of from the standpoint of the technical questions which should be raised.

For the purposes of this study inputs have been classified as: (1) Legal criteria (statutes, ordinances, court decisions, etc.), (2) administrative policies (established administrative procedures), (3) budget policies (budget estimates, ceilings, allotments, plans, etc.) and (4) technical criteria (engineering feasibility studies, construction standards, etc.). Although a large number of subjective value preferences (assumptions about actors' motives, intentions, prejudices, etc.) also become important inputs, no way was found to classify them in a replicable manner.

Table XV shows the percentage of each type of input occurring in the governmental and non-governmental subdecision setting respectively.

TABLE XV

SUBDECISION INPUTS OCCURRING IN GOVERNMENTAL AND NON-GOVERNMENTAL SETTINGS

Input	Percent By Decision-Making Setting	
	Government (211)	Non-Government (39)
Legal criteria	40	23
Administration policy	32	21
Budget policy	11	0
Technical criteria	27	56
	100	100

As would be expected, the largest number of inputs (211) occur in the governmental setting, and such inputs are distributed quite evenly among legal, administrative policy and technical criteria. In the non-governmental setting the majority of inputs (56%) are technical criteria. The frequent use of technical consultants by non-governmental groups accounts for a large proportion of these inputs. Such preoccupation with technical inputs by non-governmental groups is understandable, since such groups will have much less concern with legal, administrative or budgetary justifications than the government agency.

The Consequences which ensue from subdecisions in which inputs are utilized are presented in Table XVI.

TABLE XVI

DISTRIBUTION OF SUBDECISION CONSEQUENCES WITH TYPE OF INPUTS

	Percent of Subdecision Consequences Related To Inputs			
Consequence	Legal Criteria	Administration Policy	Budget Policy	Technical Criteria
Expression of Needs	16	28	20	19
Deter Resolution	37	13	28	17
Resolve Differences	14	14	9	5
Public Reaction	7	6	0	15
Government Reaction	24	37	48	37
Other	2	2	5	7
	100	100	100	100

The negative import of legal inputs is most noticeable. Thirty-seven percent of the legal inputs was associated with subdecisions which resulted in deterring resolution. It should be noted, though, that 28% of the budgetary inputs was also associated with subdecision actions which had this Consequence.

Administrative policy, budgetary, and technical inputs were most commonly associated with subdecisions which had governmental reactions. As such, they represent inputs which facilitated the ongoing decision-making process.

Legal criteria and administrative policy were both more important than budgetary policy or technical criteria in the resolving of differences. The importance of legal criteria, then, both in subdecisions resulting in conflict and compromise becomes quite evident. The use of administrative policy inputs was much more likely to be associated with actions which facilitate accommodations (expression of needs, resolve differences) than with those which block or delay the decision process (deter resolution).

D. Dominant Actors

A total of 1673 actors and groups participated in the 671 subdecisions identified in the 17 cases studied. The participation of these actors and groups has been discussed in previous sections of this report. But were some actors or groups more important than others? Which ones initiated the subdecision Actions? Which ones were participants in several subdecisions? And finally, can the most important actor be identified in each case?

Table XVII shows the percent of subdecisions initiated by local government, federal-state government and non-government actors and groups.*

---

* The initiating actors and multiple participating actors discussed in this section of the report apply to only 15 of the 17 cases analyzed. Such data was not readily available on the Detroit Metropolitan Airport and the Lodge Expressway cases.

TABLE XVII

PERCENT OF SUBDECISIONS INITIATED BY DIFFERENT ACTORS AND GROUPS

Actors and Groups	Percent Initiating Subdecision Actions	
Local Government		50
Undifferentiated	9	
Chief Executive	22	
Department Head	33	
Technical	9	
Legislature	27	
	100	
Federal-State Government		11
Executive	73	
Legislature	27	
	100	
Non-Government		39
Single Purpose	12	
Multiple Purpose	39	
Issue-created	28	
Clientele	8	
Unaffiliated	13	
	100	100

It will be noted that governmental actors and groups initiated the Actions in 61% of the subdecisions. Of the 11% of all subdecisions in which Actions were initiated by federal-state actors and groups, the executive branch initiated 73% of the subdecisions and the legislature 27%. Considering local government only (accounting for 50% of all subdecisions), we see that department heads initiated the largest percentage of subdecision actions (33%), while a very small proportion were initiated by technical personnel (legal counsel, design engineers, etc.).

In turning to the non-governmental actors and groups (accounting for 39% of all subdecisions), we see that 39% of these initiators were identified with multiple purpose permanent groups and actors, and only 12% with single purpose permanent groups and actors. As there were more single purpose actors and groups than multiple purpose (as noted in the previous sections), it is obvious that the latter are much more important in initiating activity effort. The same is true for the relationships between single purpose and issue-created initiators. Comparatively, there were far fewer issue-created actors and groups than single purpose and yet 28% of all non-governmental initiation was by issue-created actors and groups. Finally, the fact that only 13% of the non-governmental initiators is represented by unaffiliated actors emphasizes the small extent to which unorganized or unaffiliated behavior affects the decision process, quantitatively at least.

Some initiators, of course, will only take part in one subdecision in a case. In addition, some participants who initiate no actions will take part in several subdecisions. The percentage of multiple initiators and multiple participants (initiating and participating in two or more subdecisions respectively) involves about the same composition of local government, federal-state government and non-government personnel as shown in Table XVIII. The internal composition of participation for local government and non-government, however, varies for initiation and participation in the manner shown in Table XIX.

Among governmental personnel, chief executives tend to be more active in initiation than in participation; while the reverse is true for technical personnel. Department heads are important as both initiators and participants. In

TABLE XVIII

DISTRIBUTION OF MULTIPLE INITIATORS AND PARTICIPANTS

Actors and Groups	Percent of Multiple Initiators	Percent of Multiple Participants
Local Government	56	57
Federal-State Government	11	12
Non-Government	33	31
	100	100

TABLE XIX

IDENTIFICATION OF INITIATORS AND PARTICIPANTS INVOLVED IN TWO OR MORE SUBDECISIONS

Local Government	Percent of Multiple Initiators	Percent of Multiple Participants
Undifferentiated	10	12
Chief Executive	21	15
Department Head	35	30
Technical	8	15
Legislature	27	27
Judiciary	--	2
	100	100
Non-Governmental		
Single Purpose	15	21
Multiple Purpose	25	23
Issue-created	34	26
Clientele	11	15
Unaffiliated	15	16
	100	100

other words, the chief executive usually initiates activities when he is involved; department heads are important in both subdecisions in which they initiate activity and in which they react to activities initiated by others; and technical personnel primarily react to activity effort initiated by others.

For non-governmental actors and groups, issue-created personnel are the most frequent initiators, although they are also frequent participants in actions initiated by others. Single purpose actors and groups, on the other hand, are more frequently participants than initiators of Action. The other non-governmental actors and groups are about equally involved in initiation and participation.

Up to this point, the domination of governmental actors in the decision-process is most apparent. If one turns to a consideration of the single primary actor (who initiated the most subdecisions) in each of the cases, this point is further emphasized as shown in Table XX.

TABLE XX

PERCENT OF SUBDECISIONS INITIATED
BY EACH TYPE OF PRIMARY ACTOR

Primary Actor		Percent
Local Government		72
Undifferentiated	11	
Chief Executive	41	
Department Head	41	
Legislature	7	
	100	
State Government		13
Non-government		15
Multiple Purpose	68	
Issue-created	32	
	100	100

Local governmental personnel, as represented mainly by the chief executive or a departmental head, tend to be the primary actors initiating the most subdecision Actions. For the non-governmental personnel, multiple purpose groups dominate the primary actor activity. In none of the cases was the primary actor's major affiliation with a single purpose group.

And what were the Consequences of the Actions initiated by these primary actors? Table XXI shows the relative distribution of the types of Consequences resulting from subdecision Actions initiated by the primary actors.

TABLE XXI

CONSEQUENCES OF SUBDECISION ACTIONS INITIATED BY PRIMARY ACTORS

Consequence	Percent
Expression of Needs	20
Deter Resolution	22
Resolve Differences	13
Public Reaction	18
Government Reaction	45
	100

As may be noted, nearly half of the Actions resulted in a government reaction. If this Consequence is analyzed in more detail, it is found that the majority of such "government reactions" involved the commitment of a government body to some course of action or other. The dominant Consequence of participation by these primary actors is, then, "government commitment". It is therefore evident that these primary actors are in fact controlling actors in the decision process.

E. Legal Actions Obstructing the Decision Process

The question of legal actions taken to obstruct or delay the decision process has been considered in the discussion of those Actions which resulted in "deterring resolution".

Appeal to the courts through lawsuits is commonly assumed to be so important in this respect, however, that it is worthwhile to examine 17 cases studied to determine how many times the courts were in fact utilized to accomplish this end; and where used, how many times the Action was successful.

In no case was the instigation of such a legal Action attempted more than once and in the majority of the cases such Actions did not even occur once:

		Number of Cases in which a lawsuit was or was not instituted
NO		12
YES		5
Successful	1	
Unsuccessful	4	

It will be observed that even in those 5 cases where a lawsuit was instigated to obstruct the decision process, it was successful in accomplishing this purpose in only one case.

In the 5 cases which dealt with airport decision-making, such legal action was employed in only one case, and in that instance was unsuccessful in obstructing the decision process.

One may generalize, then, that the lawsuit was an instrument seldom used to obstruct the decision process in the 17 cases studied and when used was rarely successful in accomplishing that end.

It is possible, however, that either the use of or the threat to use legal action may influence the decision-flow -- by limiting decision-makers' perceived alternatives, for example. In the cases studied, legal actions played too minor a role in decision-making to explore these possibilities.

IV. DISCUSSION AND CONCLUSIONS

Any generalizations drawn from the findings of this study must be qualified by the limitations of the source materials. Since each case study was written by a different author and none of them was written from the perspective of the methodology presented in the report, there were severe limitations of data accessibility involved. Furthermore, inasmuch as there were few case studies available on airport-community decision-making, cases had to be selected which would reflect a balanced representation of public decision-making likely to occur in a metropolitan community. In the selection process, however, care was taken to include as many cases as possible which had either direct or indirect relevance to the airport-community decision process. Thus five cases dealing with airport operation and location, one case involving highway location, and four cases concerned with land use were included.

Data limitations also precluded any possibility of developing a qualitative classification of subdecisions. In other words, were some subdecisions more important or crucial than others? Nor could the relative roles played by different types of actors and groups be identified in other than a quantitative sense. Finally the possibility that absolute as well as relative time considerations may be important in the decision-flow could not be considered from the limited information available in case studies. Field application of the approach would be necessary for such refinements to be reflected in the findings.

It does appear, though, that a sufficiently clear pattern of behavior emerges from the findings that a set of hypotheses can be proposed for empirical validation. Although the number of subdecisions involved in the airport cases were not sufficient to justify a statistical analysis of these cases only, the data collected on these cases were observed to form the same general patterns as were observed for all cases in the body of this report. There does seem to be some justification, then, for suggesting that the following hypotheses merit empirical testing in the airport-community context and provide at least gross, tentative characteristics of normative behavior in decision-making in this context:

1. The largest proportion of actions which occur in the decision-making process occur in a governmental setting.

2. Actions may be identified as those which seek information and/or support and those which state a policy position.

3. A larger proportion of Actions which seek information and/or support occur in the administrative governmental setting than in any other setting, and such actions occur throughout the course of the decision process. Information and/or support seeking actions in the non-governmental setting occur most frequently in the second quarter; those in the legislative governmental setting occur most often in the third quarter.

4. Actions involving policy statements occur with about equal frequency in the administrative governmental and the non-governmental settings, with fewer such Actions occurring in the legislative governmental setting. In the non-governmental setting, such Actions occur most frequently in the first and second quarters of the decision process. Those occurring in the administrative government setting are spread out about equally through the decision process; while those associated with the legislative setting appear most frequently in the last two quarters.

5. The largest proportion of the actors and groups involved in the decision process is affiliated with local government. Participation of such actors and groups appears about equally distributed throughout the course of the decision process. The largest proportion of non-governmental actors and groups involved in the decision process is affiliated with single purpose permanent organizations. Their participation is most active in the second and third quarters. Issue-created actors and groups are most active in the second and fourth quarters; while multiple purpose permanent actors and groups participate most frequently in the third and fourth quarters. Unaffiliated actors are most active in the early stages of the decision process.

6. Local governmental actors and groups dominate participation in the governmental setting. Issue-created groups and single purpose permanent actors are the most numerous non-governmental groups and actors participating respectively.

7. The largest proportion of actors and groups in the non-governmental setting is affiliated with single purpose permanent organizations. Local governmental actors and groups and issue-created groups also participate in non-governmental Actions in significant numbers.

8. Participation by governmental actors in non-governmental settings occurs most frequently in the early stages of the decision process. Participation by single purpose permanent group actors in governmental settings occurs most frequently in the last two quarters.

9. Actions may have the Consequence of the expression of needs, deterring resolution, resolving differences, reflecting public or government reactions. The largest proportion of Actions result in or reflect the expression of governmental reactions. Such Actions are spread about equally through the decision process. Actions which result in or reflect the expression of needs or public reactions occur more frequently early in the decision process; while those which deter resolution are most frequent in the third quarter and those which resolve differences occur most in the final quarter.

10. Actions associated with public reactions occur most frequently in the non-governmental setting; while actions associated with all other Consequences occur most frequently in the governmental setting.

11. In the governmental setting, Actions associated with expression of needs, public reactions and government reactions occur throughout the decision process. Those associated with deterring resolution occur most frequently in the third quarter and those associated with resolving differences in the final quarter.

12. In the non-governmental setting, Actions associated with the expression of needs and public reactions

occur most frequently early in the process, those associated with governmental reactions occur most in the first and last quarters and those associated with deterring resolution occur about equally throughout the decision process.

13. The relation of actors and groups to Actions classified according to Consequence reveals that governmental actors and groups are much preoccupied with responding to Actions initiated by others (government reaction) but also participate in a significant number of Actions which deter resolution. Permanent non-governmental actors and groups are frequently involved in Actions associated with public reaction and the deterring of resolution. Issue-created groups are about equally involved in Actions which are associated with public reaction, government reaction and the deterring of resolution.

14. The most frequently used inputs in the governmental setting are legal criteria, administrative policy, and technical criteria. Those found most frequently in the non-governmental setting are technical criteria.

15. The use of legal criteria is most often associated with Actions which deter resolution. Administrative policy, budget policy and technical criteria are most often employed in Actions which are associated with government responses (government reaction).

16. Governmental actors and groups initiate more Actions than non-governmental actors and groups. The most frequent governmental initiators are chief executives and department heads. Among non-governmental actors and groups, multiple purpose permanent group actors initiate the largest percent of the Actions. Only a small proportion of Actions are initiated by single purpose permanent group actors and by unaffiliated actors.

17. Chief executives and department heads more frequently initiate multiple Actions in the decision process than participate in Actions initiated by others; while the reverse is true for government technical personnel.

18. Issue-created and multiple purpose permanent group actors more frequently initiate multiple Actions in the decision process than participate in Actions initiated by others; while the reverse is true for single purpose permanent group actors and clientele. Unaffiliated actors are about equally likely to be multiple initiators and multiple participants.

19. The primary actor (initiating most Actions) will most likely be a chief executive or department head. If he is affiliated with a non-governmental group, the group will most likely be a multiple purpose or issue-created group.

20. The largest proportion of Actions initiated by primary actors will result in governmental commitments.

21. Legal Actions are not frequently used to bloc the completion of the decision process, and when resorted to, are seldom successful in accomplishing this end.

In summary, these hypotheses suggest that the governmental administrative agency dominates the decision process. Most Actions are initiated in a governmental setting, the largest proportion of initiators and participants in Actions are governmental personnel, the primary actor is usually a chief executive or departmental head. Governmental administrative personnel also engage in more Actions which seek information and/or support than any other type of actors.

Non-governmental actors, on the other hand, initiate primarily Actions which express policy views reflecting needs, community reaction to governmental plans and activities or opposition to proposed Action. Actors affiliated with single purpose groups are the most numerous of the non-governmental actors, but multiple purpose actors and groups and members of issue-created groups are more likely to initiate and participate in more than one Action. The timing of the participation of non-governmental actors and groups is thus logical: single purpose actors being most active in the second and third quarters, and multiple purpose actors and groups in the third and fourth quarters. Issue-created groups tend

to be created in the second quarter in response to the activities of single purpose groups and unaffiliated actors expressing needs in non-governmental settings in the first and second quarters. The base of community response is broadened with the increased activities of the multiple purpose groups in the third and fourth quarters. Finally, where issue-created groups are formed, they tend to become most active in the later stages of the decision process as a bridge between the governmental and non-governmental actors and groups. The primary actors concerned with reaching consensus, however, and with legitimatizing such actions are the governmental actors and groups.

GLOSSARY

accommodation the process by which actor participants or organizations adjust their plans and/or objectives to make them compatible with the plans and/or objectives of other actor participants or organizations. (e.g. a neighborhood group agrees to the relocation of a roadway provided that they are furnished with adequate accessways to and from the relocated facility.)

Action an overt activity engaged in for the accomplishment of some perceived end.(e.g. a meeting is held, a vote is taken, a letter of protest is written, etc.)

actors the participants in an Action or Actions.

clientele an individual or group served by another organization. (e.g. airline companies are served by the FAA by being provided flight information, air traffic guidance, etc.)

Consequence the result of an action in terms of the resolution of a decision. (e.g. a public hearing was held which resulted in antagonizing the citizenry; a vote was taken by the council which resulted in the enactment of a law, etc.)

decision a determination on a future course of action which alters, broadens or restricts the plans or objectives of the organization involved and requires the expenditure of resources and/or the allocation of power in a systematic fashion to accomplish the end sought.

decision-flow the sequence of Actions taken, including the stimuli and Consequences which tie each specific Action to other Actions, to arrive at a decision.

generalized reactions attitudes perceived as the result of inferences drawn from observed or reported behavior. (e.g. from the applause which accompanied the speaker's remarks, it was assumed that the audience was in general agreement with the speaker's viewpoint; the newspaper reported that there was widespread disagreement in the community over the proposed freeway plan, etc.)

group an association of individuals joined together by mutually agreed upon role-relationships for the organized accomplishment of some end or ends.

Input types of information used to decide upon what Action to take in a subdecision. (e.g. budgetary criteria, technical criteria, legal criteria, etc.)

initiator actor or actors who exercise the initiative in response to a stimulus (e.g. actor A issues a press statement; administrator B directs his subordinate to issue the license; actor C writes a letter to his city councilman, etc.)

issue-created group a group which is formed or comes into being as a result of the issue upon which a decision must be reached, and which normally remains in existence only until an acceptable decision has been arrived at (e.g. the airport manager formed an advisory committee to study the parking problem; a community noise abatement council was organized by the residents of the area, etc.)

legitimize to give community sanction (usually through the enactment of laws) to the exercise of power and/or the use of resources for the accomplishment of agreed upon ends (e.g. the city council enacted an ordinance which authorized the construction of the facility)

methodology means by which data are ordered in a logical manner to reflect interrelationships.

multiple initiator actor who initiates Action in two or more subdecisions in a case.

<u>multiple participant</u> actor who participates in two or more subdecisions in a case.

<u>multiple-purpose group</u> a group which represents or alleges to represent the viewpoints and values of more than one type of social and/or economic group or interest in society (e.g. a league of women voters speaks for more than some voters, a chamber of commerce for more than some business interests, a civic association for more than some civic enterprises, etc.).

<u>primary actor</u> the actor in each decision-flow who initiates the largest number of Actions.

<u>participation</u> to play some role in initiating or considering activity effort which has some bearing on the outcome of an Action (see actor and Action).

<u>response</u> the activity effort engaged in by participants in a subdecision as the result of a stimulus or stimuli (see Action).

<u>single-purpose group</u> a group which represents or alleges to represent the viewpoints and values of a single type of social and/or economic group or interest in society (e.g. a bar association, a labor union, a real estate association, an airline company, etc.).

<u>stimulus</u> a circumstance which triggers a response; usually, but not necessarily, stemming out of the Consequence of a previous Action (e.g. adverse criticism of a rate increase by a city utility causes the city council to call a public hearing (stimulus) to provide the basis for reconsideration of the Action taken).

APPENDIX A

CLASSIFICATION OF SUBDECISION CHARACTERISTICS
FOR CASE HISTORY DECISION-FLOW STUDIES

A. Action types

1. Government (administrative) actions

a. Information-support seeking

(1) initiate contact with other government reports

(2) initiate contact with public

(3) establish decision-making mechanisms

(4) interaction with other government officials

b. Statement of policy position

(1) agree to request

(2) reject request

(3) make public statement

(4) request delay

(5) prepare report

(6) issue report or formal position

(7) delay or refusal to act

2. Government (legislative) actions

a. Information-support seeking

(1) request information

(2) request action or concurrence of other government agency

(3) call public hearing

(4) establish decision-making mechanism

(5) introduce matter for consideration

b. Statement of policy position

(1) veto

(2) schedule vote on matter for consideration

(3) make public statement

(4) request delay

(5) prepare report

(6) issuance of report or formal position

(7) delay or refusal to act

3. Non-governmental actions

a. Information-support seeking

(1) formation of and/or meetings of ad hoc group or committee

(2) meeting(s) of permanent group or committee

(3) establish decision-making mechanism

(4) contact government official

(5) communication between non-government actors

b. Statement of policy position

(1) make public announcement

(2) prepare report

(3) issuance of report or formal position

4. Governmental deliberation
    a. Initiate action
        (1) proposal
        (2) counterproposal
    b. Accept actions under consideration
        (1) agreement
        (2) accept proposed approach
        (3) accept matter being considered
    c. Reject or delay actions
        (1) dissention
5. Non-governmental deliberation
    a. Initiate action
        (1) proposal
        (2) counterproposal
    b. Accept actions under consideration
        (1) agreement
        (2) accept proposed approach
        (3) accept matter being considered
    c. Reject or delay action
        (1) dissention

B. Consequence types
    1. Expression of needs

a. Need for action or change

b. Felt need for information

c. Communication of position

2. Deter resolution

a. Indecision

b. Contingent threat

c. Blocking action

3. Resolve differences

a. Compromise

b. Legitimization

4. Public reactions

a. Approval

b. Disapproval

c. Concern

d. Weakened

e. Strengthened

f. Need for

g. Commitment

h. Dissipates

5. Government reactions

a. Approval

b. Disapproval

c. Concern

d. Weakened

e. Strengthened

f. Need for

g. Commitment

C. Groups and actor affiliation

1. Local government

   a. Administrative

   b. Legislative

   c. Judicial

2. Federal-state governments

   a. Administrative

   b. Legislative

   c. Judicial

3. Non-governmental

   a. Single purpose permanent groups - having single functional concern

   b. Multiple purpose permanent groups - have multiple functional identifications (e.g., chambers of commerce, Leagues of Women Voters, civic associations, etc.)

   c. Issue - created groups (e.g., advisory committees, ad hoc groups, etc. whether created by government or non-government group)

d. Clientele - served by governmental agencies involved in decision

e. Unaffiliated actors

D. Inputs

1. Legal criteria

2. Established administrative policy or procedure

3. Budget policy or procedure

4. Technical criteria

APPENDIX B

CONSTRUCTING A DECISION-FLOW DIAGRAM: THE BROOME COUNTY AIRPORT CASE

The Broome County Airport case* has been chosen to illustrate how the decision-flow diagrams were constructed for the seventeen cases used in the study.

The first four pages of the case have been reproduced in Exhibit 2, with special notations added to show how the analysts identified the first three subdecisions of the case as recorded in Exhibit 1.

To begin with, the sentence on page 323 of Exhibit 2, reading:

> "Combined with this transportation situation was the existence of a community interest in aviation originating in the 1920's, stimulated by a core of active, private enthusiasts."

summarizes the initiating circumstances which constitute the initial stimulus indicated in Exhibit 1: "Inadequate transportation to and from Broome County."

This stimulus called forth a response from American Airlines which offered to serve the area if adequate airport facilities could be provided (Exhibit 2, last sentence, page 323). The Consequence of this Action was to activate local government and community leaders into efforts to meet this felt need.

Subdecision No. 1, then, consists of the stimulus, response (Action) and Consequence recorded in Exhibit 1. The only actor in the subdecision was the airline, a non-government single purpose group, since it directed its statement to the community at large. The type of Action involved is a "statement of policy" by the airline and the Consequence is a "reaction of concern (interest)" by the local government officials and civic leaders. No inputs are identifiable.

---

* Frost, Richard T. (ed.), Cases in State and Local Government, Englewood Cliffs: Prentice-Hall (1961) pp 321-336.

The stimulus of subdecision No. 2 stems out of the Consequence of subdecision No. 1 (Exhibit 2, top of page 324). Before the community can justify a new airport some authoritative body must pronounce the existing airport inadequate. This circumstance becomes the stimulus for Broome County leaders to approach the CAA for an official evaluation (response to subdecision No. 2). CAA does not indicate any willingness to act on the request which results in blocked action (Exhibit 2, second paragraph, page 324).

The actors in subdecision No. 2 are a group of civic leaders brought into existence to deal with the issue (issue-created group) and the CAA (Federal government: administrative). The initiator of the Action is the issue-created group. The type of Action is "information and support seeking," and the Consequence is to "deter resolution: blocked action."

The input in this subdecision, "established administrative policy," becomes an important basis for the CAA inaction. The Broome County request does not fall within the well-defined scope of its programmed activities; consequently CAA is hesitant to act without considerable evidence of a felt need.

The Consequence of subdecision No. 2 leads to the stimulus of subdecision No. 3, the search for other approaches to problem solution. The response to this stimulus is the community leaders request to their Congressman to intervene on their behalf (Exhibit 2, second paragraph, page 324). The Consequence of this Action is to convince CAA of the need for an evaluation on the adequacy of existing airport facilities.

In this subdecision, the actors are the issue-created group, a Federal legislator and a Federal administrative agency. The issue-created group is again the initiator. The nature of the Action is again "information and support seeking," and the Consequence of the Action is the "expression of needs: need for action."

Subdecisions No. 4 through 31 were identified and classified in a similar manner leading up to the last subdecision, No. 32, in which the decision to build an airport is legitimized.

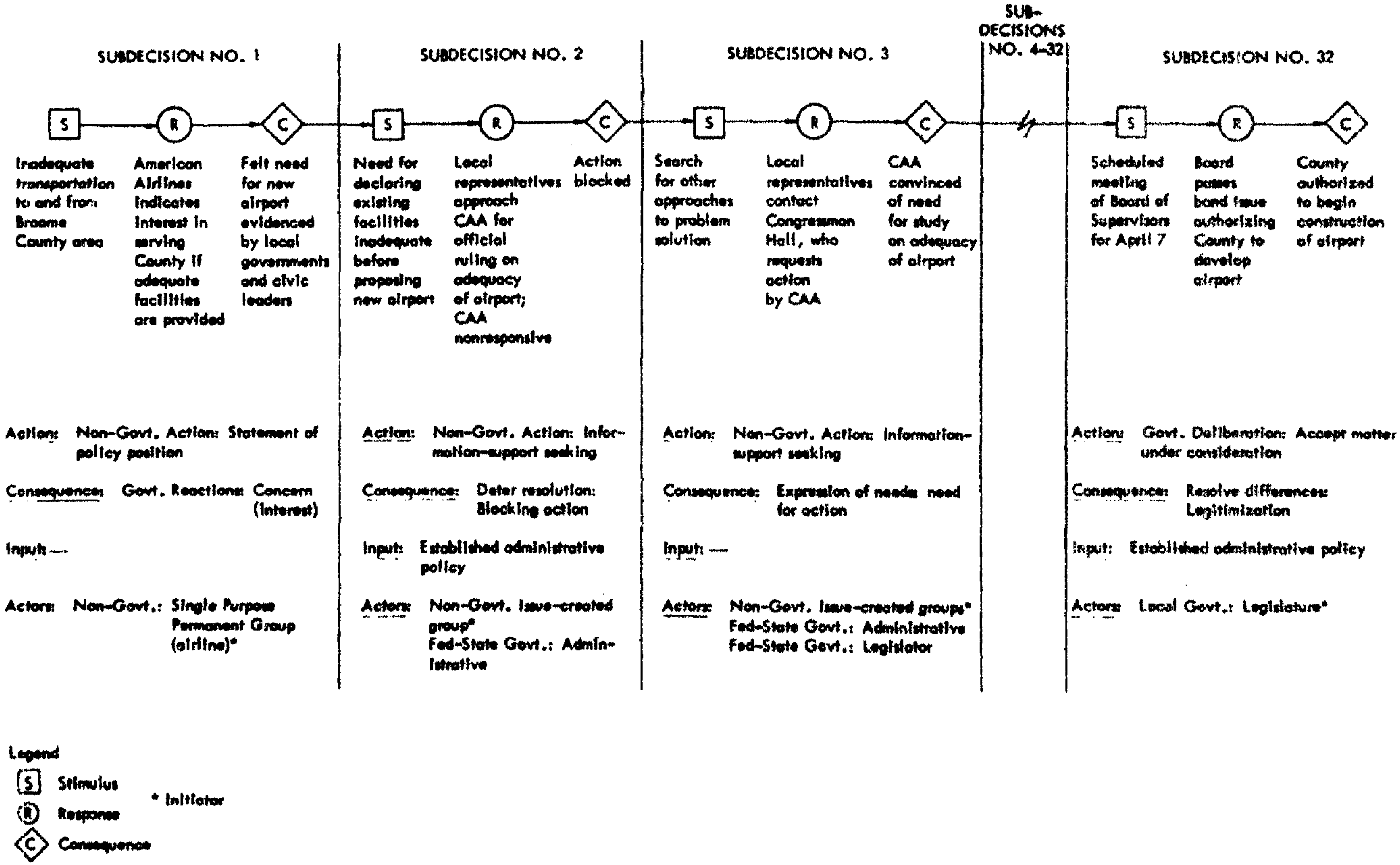


EXHIBIT 1. DECISION-FLOW DIAGRAM: BROOME COUNTY AIRPORT CASE
(Including Coded Subdecision Data)

25

THE BROOME COUNTY AIRPORT

Seymour Z. Mann

Ronald M. Stout*

Since the nineteen thirties, relations between the Federal government and American cities have increased markedly. No longer is it appropriate to speak of the neat compartmentalization among Federal, state, and local programs. There are about 100 Federal agencies which supply some kind of service to cities. Whether these services are coordinated in any way is a subject for discussion elsewhere; the important fact is that in programs such as health and welfare, education, highways, or urban redevelopment, Federal-local relations are organized on a functional basis, and they are substantial.

One of these intergovernmental programs began with the Federal Airport Act of 1946, providing grants to cities for construction of airports. The act was passed in the middle of the time-span of this case.

There is no end to the argument as to the proper role for each level of government in public programs. The only reasonable comment seems to be that the pressure of forces and events (as with the sudden involvement of the Federal government with the cities in the depression of the thirties) sets the limits of intergovernmental participation. The future of this involvement, whatever characteristics it takes on, will surely be one of complexity and growth. This is because the Presidency is pre-eminently an urban office, while state legislatures—who should be responding to the needs of cities—are too often rurally-based and have failed to meet those needs. In short, much of the help which was not forthcoming in state capitals did come from Washington. One may claim that the increasing centralization is a bad thing for the democracy, but one has little difficulty discovering its cause. But having said this, one must also look realistically at state capacities in these big, urban programs. The tax bases of the states require them to compete with each other for taxable wealth. That competiton often takes the form of reluctance to impose taxes lest the sources—when able—decide to locate in another state. There is no pat answer to this the trickiest problem of our federalism. It plagues progressive state officials who would otherwise set forces in motion which might respond more fully to urban needs.

For those who have a special interest in problems such as airport construction in metropolitan areas, a more comprehensive treatment of the political forces operating in the Broome County case can be found in a longer study by Seymour Mann which appears in Politics in New York State: Selected Papers, *a publication of the Syracuse University Press, sponsored by the Citizenship Clearing House.*

---

* One of the authors is grateful to the Intercuniversity Case Program for a grant which made field work on this case possible.

321

EXHIBIT 2. ILLUSTRATION OF DECISION - FLOW ANALYSIS

INITIATING CIRCUMSTANCES

Should Broome County establish a county airport? This issue came into sharp focus in 1944, and was resolved in 1947, by interaction among organized aviation and other interest groups, industrial leaders, the Broome County Planning Board, state and Federal aviation officials, political leaders, and the Broome County Board of Supervisors. However, the chain of events which created the issue originated in the late 1920's, and these events were influenced by certain political and economic characteristics of the area.

The metropolitan area of Broome County, located on the "southern tier" of New York State on the Pennsylvania border, has an urban core known as the "triple Cities," namely, Binghamton, Endicott, and Johnson City. The core is ringed by fast-growing suburbs and rural areas beyond. Other typical metropolitan characteristics are its rapid overall population increase of 38.2% from 1930 to 1957 (149,000 to 203,250) constituting the highest percentage increase of the six upstate metropolitan areas, and the changing ratio of central city to outside area growth, with the latter growing more than the former.

The pattern of economic growth in Broome County typically involves a shift from agriculture to industry. More than 200 manufacturing firms produce a wide variety of products. Among these are firms of national prominence, such as International Business Machines (IBM), Endicott Johnson Corporation (shoes), Kroehler Manufacturing Company (furniture), Ansco Corporation (photographic supplies), and Link Aviation, makers of Link Trainers and instrument flight training devices. Agriculture is still important to the county, with some 2,000 farms producing principally milk, eggs, poultry, oats, and hay.

Broome County government is traditional in form, with a Board of Supervisors composed of thirteen members from Binghamton and sixteen from the towns. There is also the customary list of elected "row officers." Final responsibility for executive coordination as well as legislation rests in the Board. In the absence of a single executive, the Supervisors exercise administrative control over the line departments through committees, with informal coordination by the Chairman of the Board. He appoints standing and special committees and traditionally gives more time to his job than the others.

Broome County politics are one-party Republican. Despite expanding industrialization and urbanization, the number of Democratic mayors in the urban centers has been few since 1900. Controversy is not absent, but it takes the form of rural-urban conflict over kinds of services and related tax issues, or factional intra-party disputes.

Exhibit 2 (Cont.)

Of immediate pertinence to the airport issue was the general transportation situation, particularly as it existed in 1944, and the presence of organized groups dedicated to aviation for some time before 1944. Broome County was off the main line, as it were. None of the big U.S. highway routes east and west served the area directly. Railroads connected the County with the Midwest and New York City or Albany, but many persons felt that metropolitan Binghamton-Broome County lacked direct rapid transportation to Philadelphia, Pittsburgh, New York, and Washington. Passenger rail service was particularly limited, and it was believed that socio-economic development demanded more rapid transportation to the larger centers in the East.

INITIATING CIRCUMSTANCES (Cont.)

Combined with this transportation situation was the existence of a community interest in aviation originating in the 1920's, stimulated by a core of active, private enthusiasts. These included Dr. Frank Moore, an Endicott surgeon and Trustee of the Village, who became chairman of the Tri-Cities Airport Commission; Mr. George W. Johnson, son of the founder of Endicott-Johnson and board chairman of the company during this controversy; Mr. Charles F. Johnson, president of the company; and Mr. Edwin Link, who initiated his aircraft training devices at the West Endicott field provided by the Johnsons as a flying area open to all. The community interest in aviation took its first organized form in an Aero Club, starting in 1927, and then in a Tri-Cities Joint Aviation Committee composed of representatives from the Chambers of Commerce of the three cities. Through this organization's efforts, a Tri-Cities Airport, governed by a Tri-Cities Airport Commission, was established in the mid-thirties. Its ultimate objective was eventually to attract scheduled air service.

STIMULUS, S.D. #1

Negotiations with major airlines, however, failed to establish regular service despite expenditures of some $500,000 in Federal and $230,000 in local funds to establish and develop the field. Growing concern over this, reflected in newspaper stories, was crystallized in 1943 when American Airlines indicated that although it wished to serve the Triple Cities, flight into the airport was possible only when weather conditions were almost ideal because of the airport's location and surrounding terrain. American urged that a new airport be developed which would enable dependable daily service, rather than continue to put money into a port "the very nature of whose site makes it impossible of development into a first-class airport."

RESPONSE, S.D. #1

CONSEQUENCE, S.D. #1
STIMULUS, S.D. #2

DEFINITION OF THE AIRPORT ISSUE: 1944

By 1944, certain local proponents of aviation recognized the inadequacy of the field and felt they should look for a new site. Yet their position was awkward since they felt that it would be difficult to propose a new site before the Tri-Cities Airport was being fully used and since they would rather not base a new airport on criticism of the present one. What they needed was an official ruling on the adequacy of the Tri-Cities port from the Civil Aeronautics Administration (CAA), or, after certification of scheduled airlines had been granted, for some certified line to refuse to come in.

CONSEQUENCE, S.D. #2
RESPONSE, S.D. #2
RESPONSE, S.D. #3
CONSEQUENCE, S.D. #3

CAA was approached, but its response at the time was not particularly helpful. Influential citizens then requested Congressman Edwin Arthur Hall to take up the matter with CAA in Washington. The result was an informal CAA inspection and a report submitted to CAA in Washington on February 7, 1944, which in essence stated that no improvements could make the Tri-Cities field adequate for expanded air carrier operations. CAA wrote its findings to Dr. Frank Moore, whose interest in airport development was evidenced by his leadership in establishing the Joint Aviation Committee of the Chambers of Commerce and by his chairmanship of the Tri-Cities Airport Commission.

With the letter from CAA, it was obvious to Dr. Moore that an alternative would have to be developed, and with this came the idea of an airport sponsored by the County. However, this raised problems involving what kind of a program to propose and what method to employ to bring the proposal to the Board of Supervisors. A further complication was the possible adverse effect on the existing cooperation among supporters and members of the Tri-Cities Airport Commission once the CAA decision became known.

FACT FINDING AND PLANNING PHASE: 1944-1946

Dr. Moore solved his immediate problem in the spring of 1944 when, through the chance circumstance of his treating Dr. Clement G. Bowers for an injured knee, the Broome County Planning Board was brought into the picture. Dr. Bowers was a plant scientist and a long established, well respected citizen of the County. He was the Chairman of the Broome County Planning Board which from its creation in 1937 had established itself as an impartial, non-political staff

FINAL REPORT

Contract No. FA-WA-4409

SRDS Report No. RD-65-130

Project 430-001-01R

PART IV

THE REDUCTION OF AIRCRAFT NOISE MEASURED IN SEVERAL SCHOOL, MOTEL AND RESIDENTIAL ROOMS

December 1965

Prepared By

Dwight E. Bishop

BOLT BERANEK AND NEWMAN INC.
15808 Wyandotte Street
Van Nuys, California 91406

ABSTRACT

Field noise reduction measurements in 21 school, motel and residential rooms during flyovers of jet and propeller aircraft are described. The measured noise reduction for most rooms was found to lie within or near the range of moderate noise reduction values observed in previous measurements of houses and wood frame air base buildings.

Sizeable differences in room noise reduction values were observed during successive aircraft flyovers. For jet aircraft flyovers, the rms value of the standard deviations for noise reduction measurements in school and motel rooms was 2.7 PNdB. For the four residential rooms studied, a rms value for the standard deviations of 3.4 PNdB was observed. Thus, room noise reduction variability can introduce significant variations in the indoor judgments of the noisiness of aircraft flyovers which have the same outdoor measured perceived noise levels.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

I. INTRODUCTION

In estimating the noise levels heard on the ground during flyover of an aircraft, one often wishes to estimate the reduction of aircraft noise afforded by various types of buildings. Previously reported noise reduction measurements for aircraft noise have been made primarily in residential or military air base buildings.[1,2] The measurements described in this report were undertaken to supply additional information concerning typical noise reduction values by:

a) extending the field measurements to a wider variety of buildings, particularly school and motel buildings; and,

b) providing an estimate of the variation in noise reduction one may expect during successive flyovers of different aircraft.

The school and motel measurements supplied basic technical data for establishing and checking the building noise reduction values of reference 3. The residential room noise reduction measurements were gathered during the field judgment tests of aircraft noise described in reference 4. Building noise reduction was measured in 21 different rooms in 15 separate buildings at six locations: four under the approach path, and two to one side of the takeoff path of Runway 7R-25L at the Los Angeles International Airport. Figure 1 shows the locations of the buildings and their relationship to major runways at the Los Angeles International Airport. Also shown in Fig. 1 are contours of the maximum perceived noise levels which might be experienced during operation of a four engine turbojet transport from Runway 25L.

With one exception, measurements were made in buildings constructed since 1949. And, with one exception, the buildings were typical lightweight construction -- stucco on wood frame, concrete block or brick, with single pane glass windows. The range of building types sampled in the study is obviously not complete, but is representative of some common types of present-day construction.

Preceding Page Blank

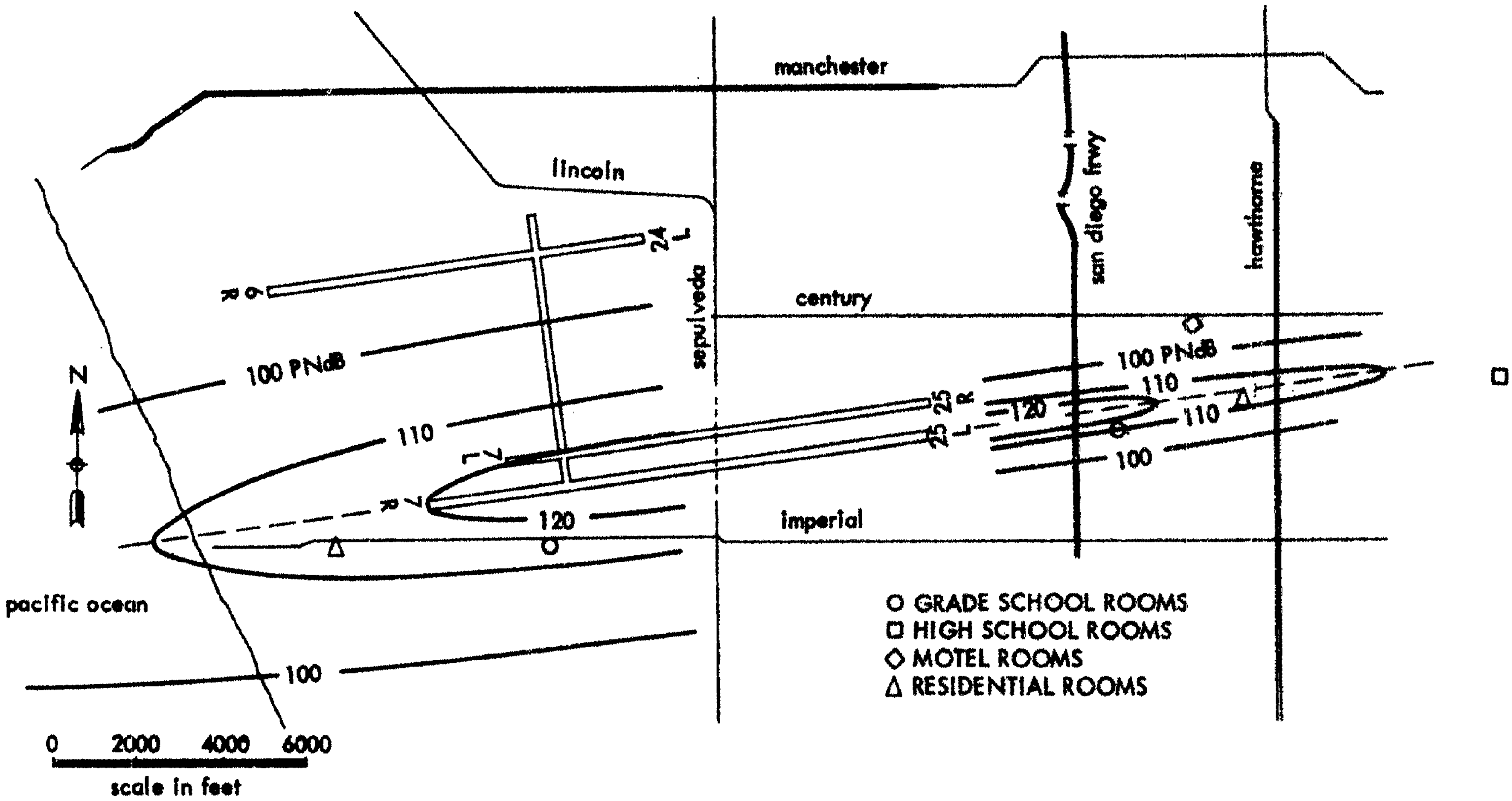


FIGURE 1. LOCATION OF BUILDINGS FOR AIRCRAFT NOISE REDUCTION MEASUREMENTS

II. MEASUREMENT AND ANALYSIS PROCEDURES

The building noise reduction was simply defined as the difference between the maximum sound pressure levels observed outside a building and inside a building during an aircraft flyover. One microphone was placed inside the room under study and another microphone placed outside the building away from the immediate influence of nearby building surfaces. The noise signals received by the two microphones during the flyovers were recorded on magnetic tape. Later, the two recordings obtained for each flyover were played back through a sound level meter, a band-pass filter or a frequency-shaping network and a graphic level recorder. The maximum values of the slowly rising and falling noise signals resulting from the aircraft flyover were then read from the recorder charts.

For many of the flyovers, the noise signals were analyzed in terms of the maximum sound pressure levels occurring in octave frequency bands. The building noise reduction was then expressed as the difference in levels measured in the individual octave bands.

We were also interested in expressing the building noise reduction in terms of the difference in perceived noise levels observed outside and inside the building.* Thus, for many of the flyovers, perceived noise levels were calculated from the octave band data.6,7/ The noise reduction was then expressed as the difference between calculated perceived noise levels. For other sets of measurements the recordings were played back through a perceived noise level network (the inverse of the 40-noy equal-noisiness contour).6/ The frequency response of this network is shown in Fig. 2. The value obtained by

---

* The perceived noise level, expressed in PNdB, is a quantity calculated from physical measurements of the noise that correlates very well with the subjective evaluation of the noisiness or annoyance of various types of noise. It has become a widely accepted means for describing aircraft noise both in this country and abroad.

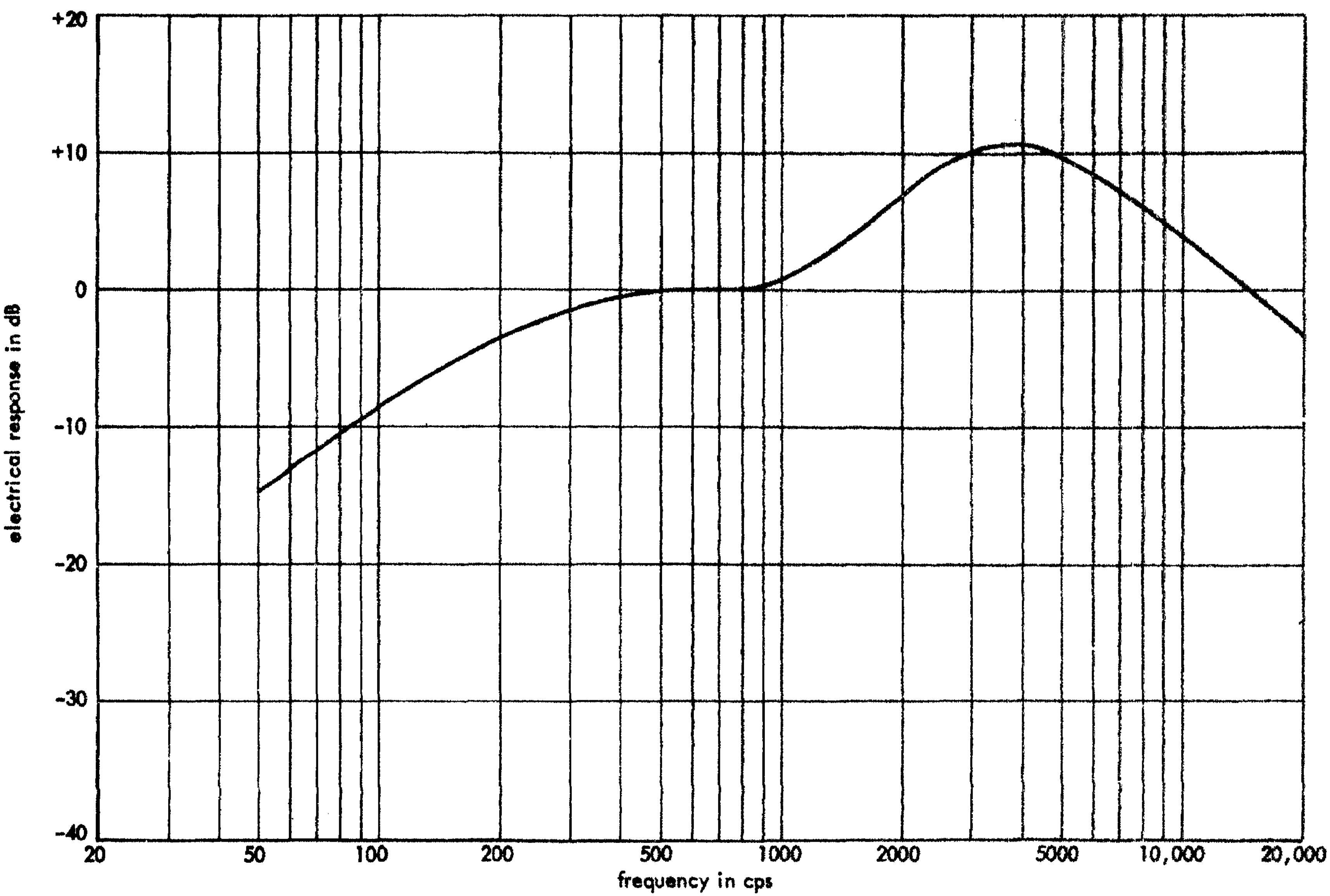


FIGURE 2. RELATIVE FREQUENCY RESPONSE OF THE PERCEIVED NOISE LEVEL WEIGHTING NETWORK (INVERSE OF THE 40-NOY EQUAL - NOISINESS CONTOUR)

playback through this network approximated the perceived noise level value calculated from the octave band measurements.[8]

For 79 sets of noise reduction measurements, it was found that the room noise reduction values, computed as a difference between the outside and inside network readings, generally agreed well with the noise reduction values given by the difference in calculated PNdB values (obtained from the octave band data). The average difference between network and calculated PNdB noise reduction values was 0.0 PNdB. The standard deviation for the set of 79 differences was 2.0 PNdB.

Definition of noise reduction in terms of maximum levels occurring during a flyover is a very useful measure of building acoustic performance. However it is not a precise or unique measure. For a particular room, this measure of noise reduction may well vary with type of aircraft and with aircraft flight path as well as with measurement position inside and outside the room. For example, because of differences in spectrum shapes and directional patterns for noise radiated by propeller and jet aircraft, the noise reduction measured in a room may be somewhat different for propeller aircraft than for jet aircraft.

To illustrate complexities in data interpretation and the possible oversimplification involved in measuring only maximum flyover values, Fig. 3 shows noise levels in the 1000 cps octave band measured outside and inside a classroom during flyovers of a piston and a jet transport aircraft on approach. A single maximum occurs outside the room, but a well-defined double peak (clearly audible) was observed inside the room. Such double peaks were observed in several classrooms having two opposing side walls each pierced with a row of single-pane glass windows when the overhead aircraft flight path was perpendicular to the window walls.

The first peak observed inside the classroom results, of course, from the noise transmitted through the windows in the wall as the aircraft approached the classroom;

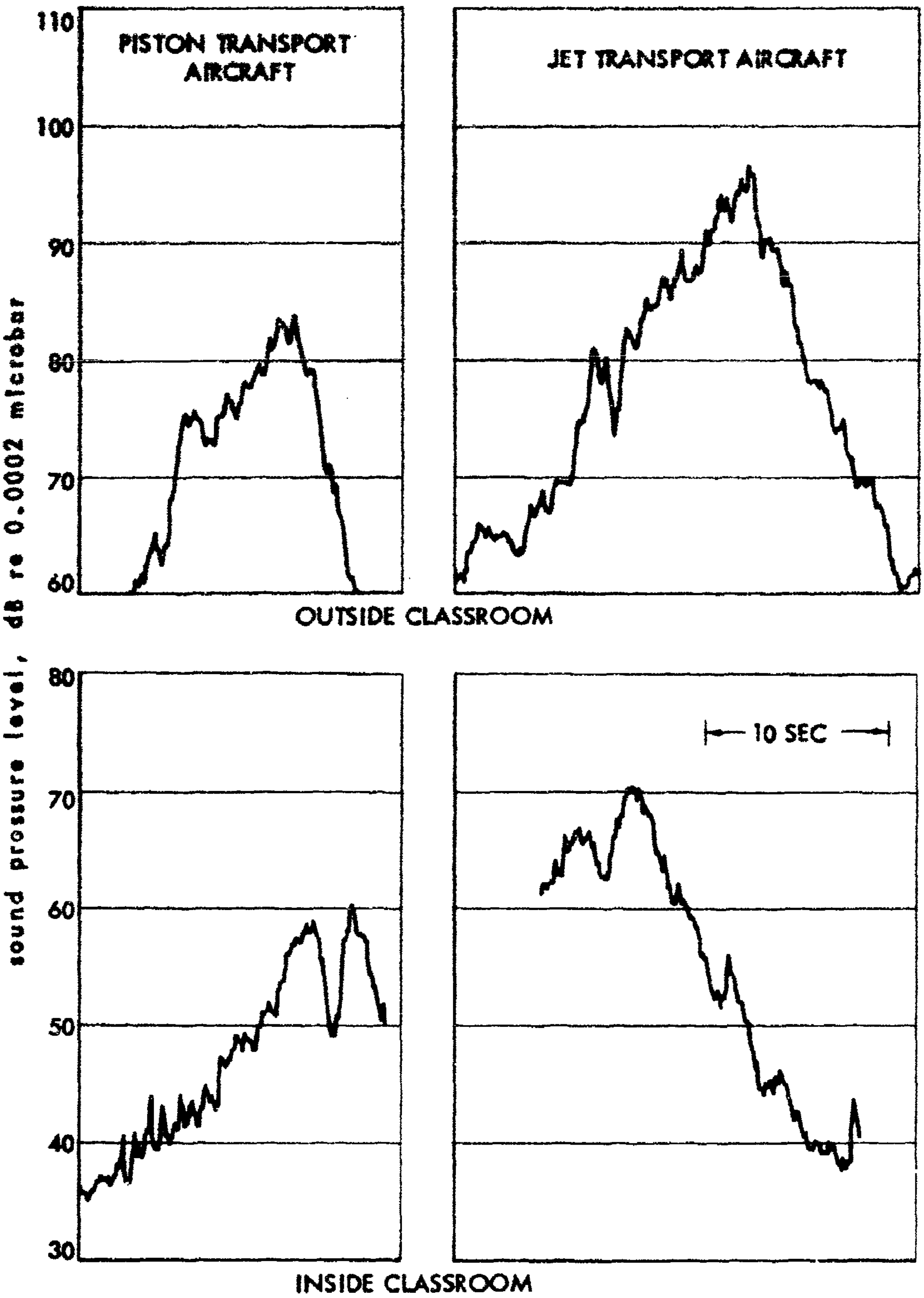


FIGURE 3. TIME RECORD OF AIRCRAFT FLYOVER NOISE IN THE 1000 CPS OCTAVE BAND SHOWING DIFFERENCES IN TIME PATTERNS INSIDE AND OUTSIDE OF CLASSROOM (Note: Time Records are not Synchronized)

the second peak from the noise transmitted through the windows on the opposite wall after the airplane had passed over the building. (One might also note that neither of the peaks observed inside the room necessarily occurred at the same time as the single peak recorded outside the room.) The two peaks in the interior sound levels well illustrate the fact established in previous building noise reduction measurements that maximum levels inside a room are governed by the weakest part of the noise barrier provided by the building structure.1/

Occasionally, during measurements under the approach path, interpretation of noise reduction measurements was further complicated by two maxima in the sound levels observed outside the building. The two maxima are due to the noise characteristics of some jet aircraft at intermediate or low-power settings. Strong radiation of fan and compressor noise in the forward quadrant produces one maximum as the aircraft approaches, followed by a decrease in level as the aircraft passes directly overhead; then another maximum in the noise occurs because of jet noise radiated from the engine exhausts.

III. NOISE REDUCTION RESULTS

A. Variation Within Rooms

Figure 4 shows the building noise reduction expressed as differences in perceived noise levels for the different school rooms. In the figure, perceived noise level differences for jet and propeller aircraft are distinguished by the shape of symbols. Measurements with windows or doors open are indicated by the open symbols. The horizontal bars represent the median value of noise reduction observed in each room for jet aircraft flyovers. The range of median noise reduction values extends from 18 to 37 PNdB, with the high value of 37 PNdB measured in a specially constructed "soundproofed" classroom. Excluding the auditorium and the soundproofed classroom, the median noise reduction values range from 18 to 31 PNdB.

Figure 5 shows the noise reduction measured during eight successive flyovers of jet and propeller aircraft in a grade school classroom located under the approach path. This classroom was of stucco and wood frame construction with large areas of single pane windows on the two side walls directly exposed to aircraft noise. Shown in the figure are the noise reduction values measured in the room with the windows closed and also with the windows on one side of the building partially opened. Lines drawn through the octave band spectra represent the median of the observed values for both the windows open and windows closed conditions.

Similarily, Fig. 6 shows the noise reduction for eight flyovers in a motel room located near the approach path. This room was on the first floor of a two-story stucco on wood frame building; only one wall in the room was exposed directly to aircraft noise.

Figure 7 shows consecutive measurements in a grade school classroom located to one side of the takeoff path. The measurements shown in the figure were all obtained during

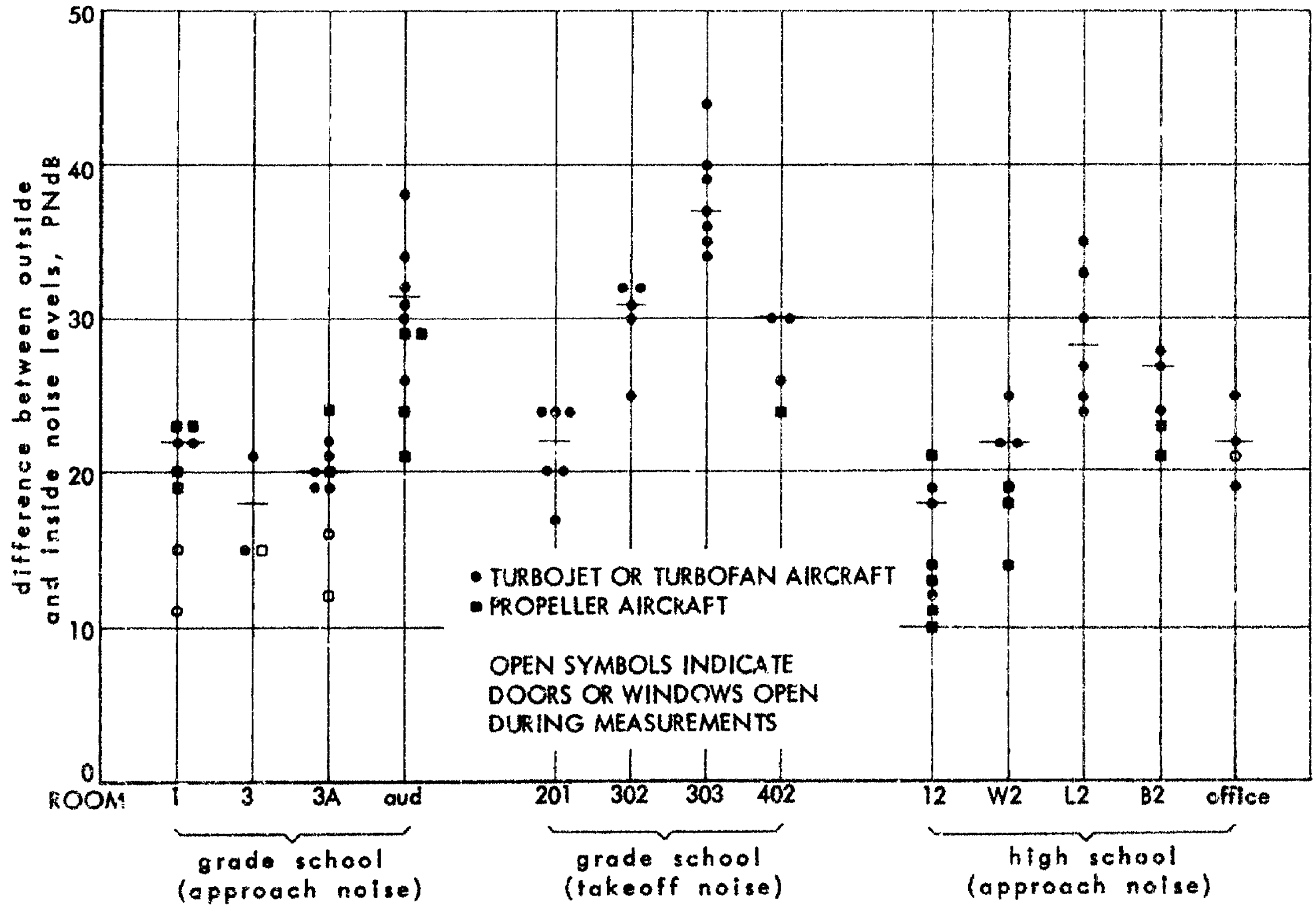


FIGURE 4. SUMMARY OF FIELD MEASUREMENTS OF SCHOOL ROOM NOISE REDUCTION

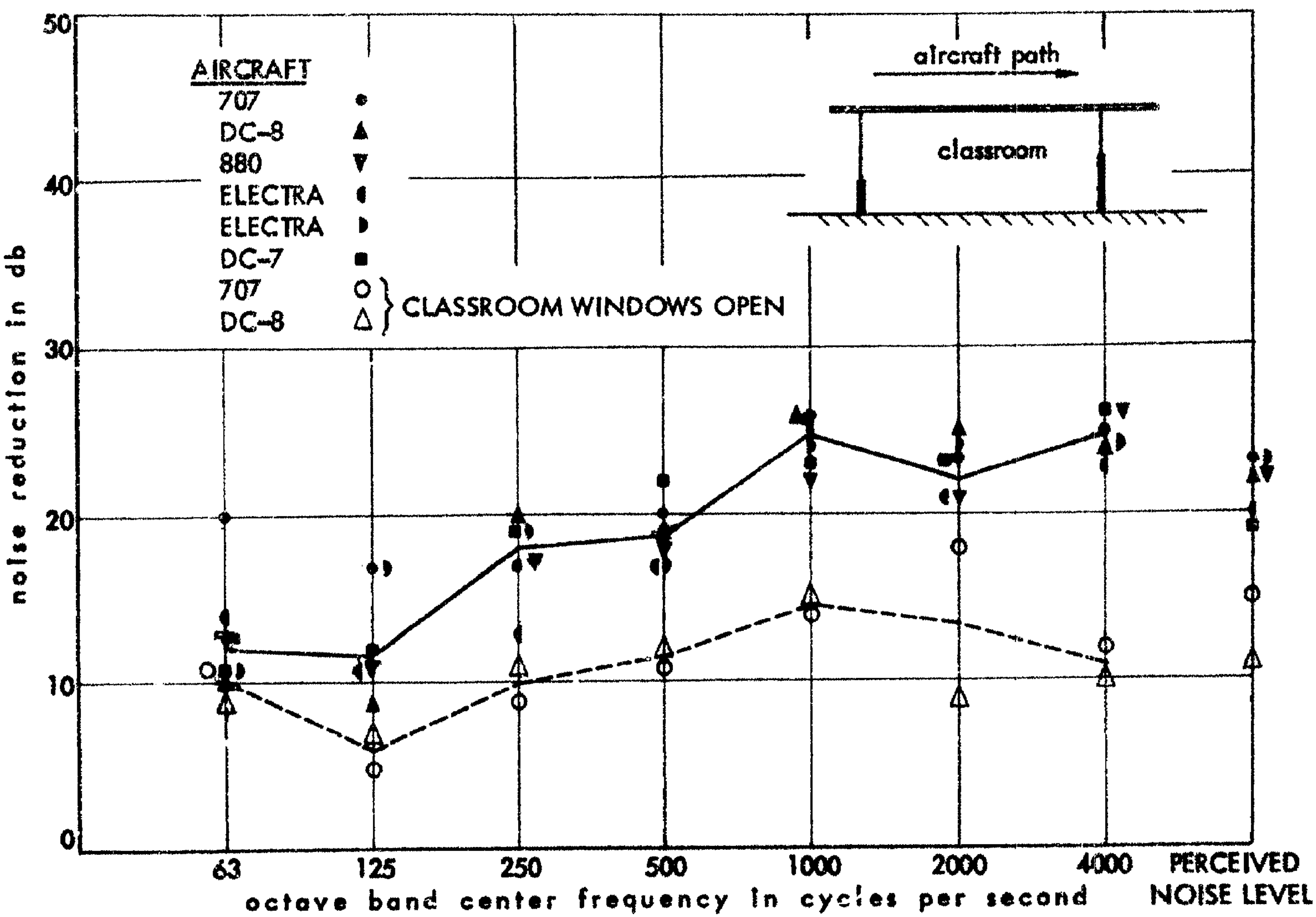


FIGURE 5. NOISE REDUCTION DURING SUCCESSIVE AIRCRAFT FLYOVERS - APPROACH NOISE, GRADE SCHOOL CLASSROOM NO. 1

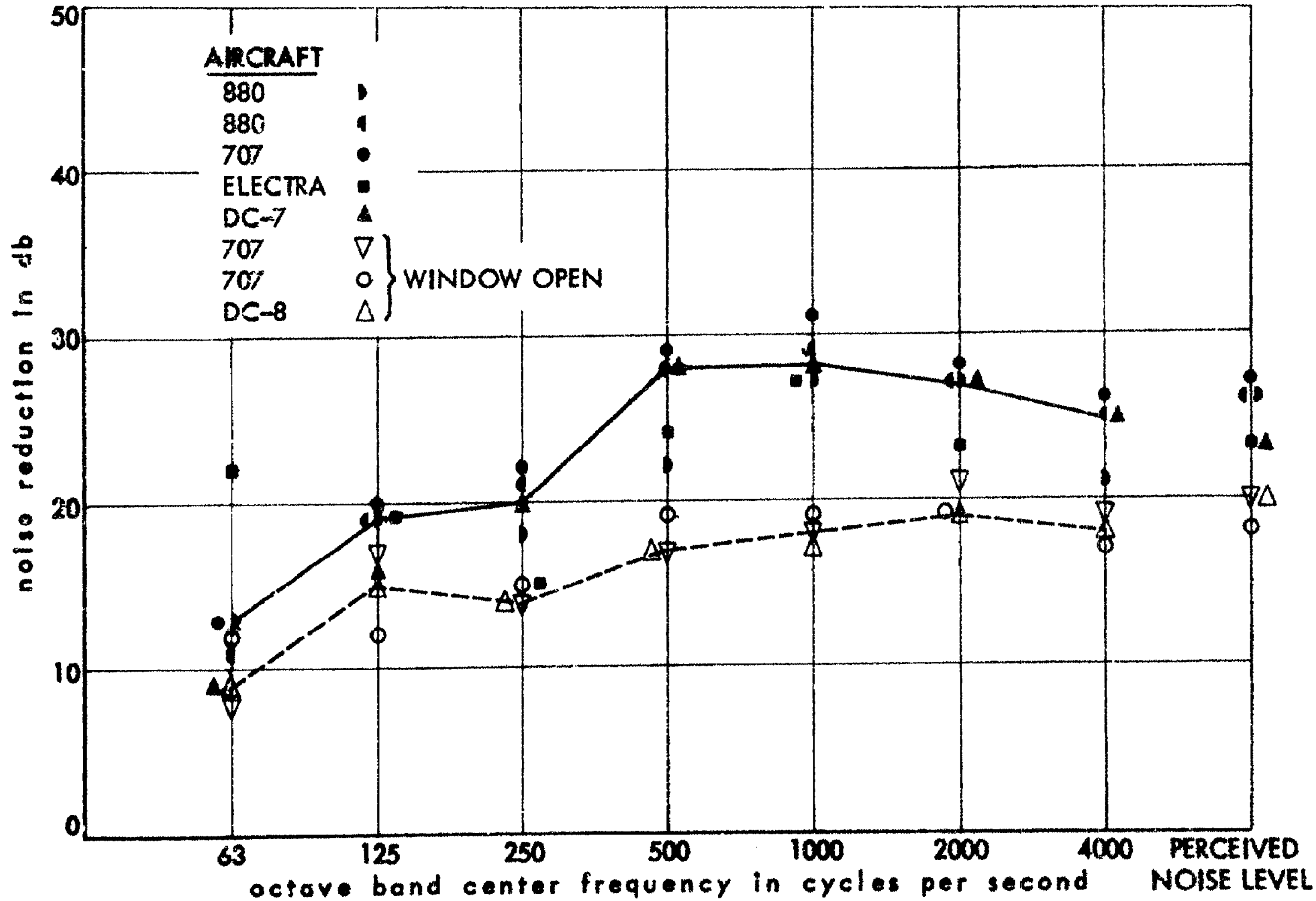


FIGURE 6. NOISE REDUCTION DURING SUCCESSIVE AIRCRAFT FLYOVERS - APPROACH NOISE, MOTEL ROOM 115

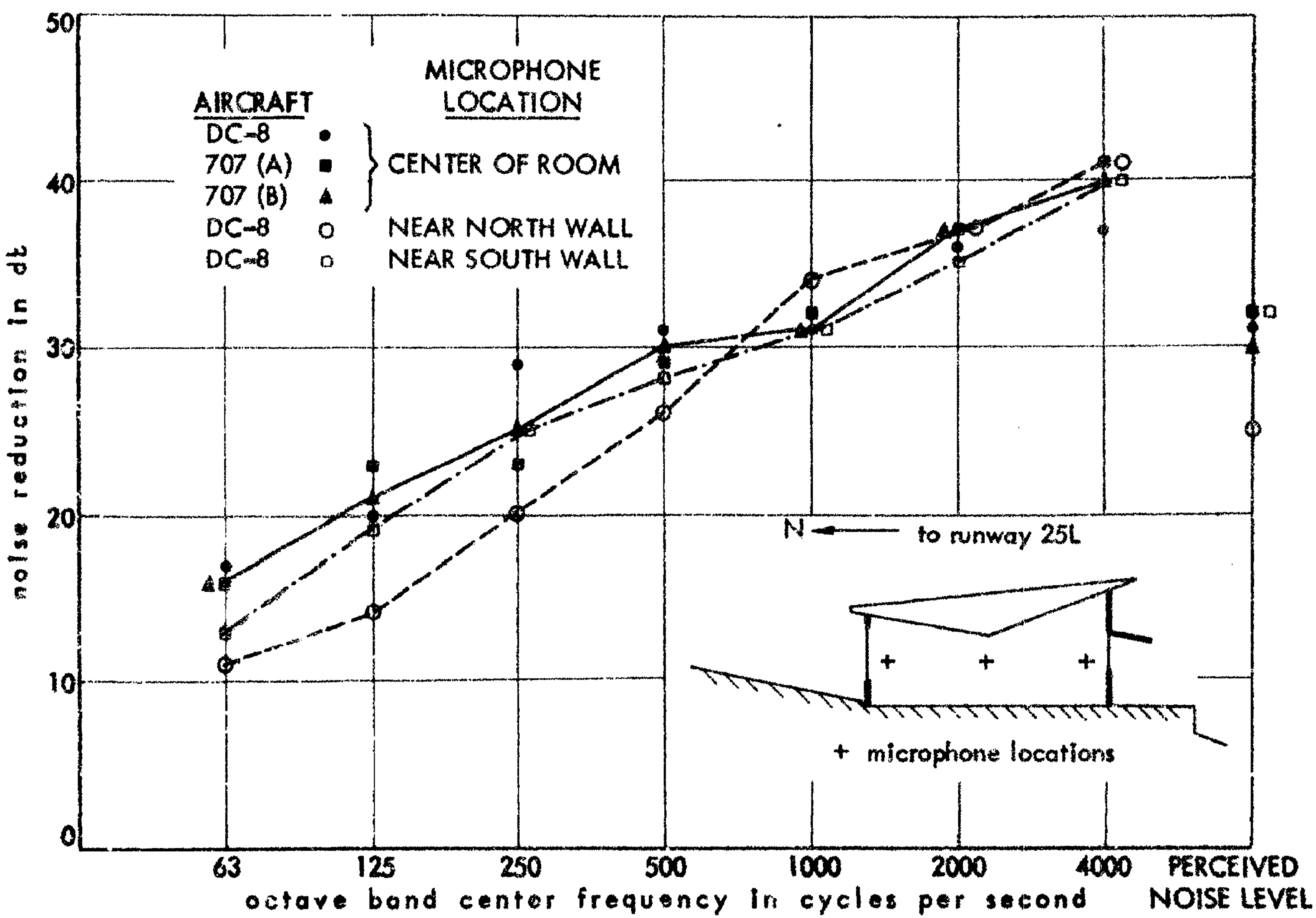


FIGURE 7. NOISE REDUCTION DURING SUCCESSIVE AIRCRAFT FLYOVERS - TAKEOFF NOISE, GRADE SCHOOL CLASSROOM 302

jet aircraft takeoffs; curves are shown for three different microphone locations in the room, one near the middle of the room, the other two near the side walls of the classroom as shown in the sketch.

Analysis of the variations in measured noise reduction yielded standard deviations ranging from 1.6 to 5.4 PNdB for the individual school and motel rooms.* The rms value of the individual room standard deviations was 3.6 PNdB considering flyovers of both propeller and jet aircraft. For reduction of jet aircraft noise only, the rms value of the standard deviations was 2.7 PNdB. The rms value of standard deviations for noise reduction observed in the different octave frequency bands from 63 to 4000 cps varied from 2.2 to 3.5 dB as shown in the fourth column of Table I.

Residential room noise reduction measurements were made in the living room and a bedroom of an apartment exposed to takeoff noise, and in the living room and a bedroom of a frame house exposed to approach noise. The mean and standard deviation values of the room noise reduction, as expressed in PNdB, are shown in Table II. The rms value of standard deviations for noise reduction observed in the different octave frequency bands, based upon a sample of 10 flyovers in each of the four rooms, is shown in the last column of Table I.

These values, varying from 2.7 to 4.3 PNdB for the various octave bands, are generally slightly larger than the corresponding values for the school and motel rooms. For both sets of standard deviations, smallest values are usually observed in the octave bands of 500 and 1000 cps, with variations increasing at the lower and higher frequencies.

---

* These variations may be roughly interpreted in subjective terms by considering that an increase of 3 PNdB reflects about a 25% increase in subjective noisiness; a 10 PNdB increase, a doubling (or 100% increase) in noisiness.

TABLE I

OCTAVE FREQUENCY BAND VARIATIONS IN MEASURED ROOM REDUCTION OF AIRCRAFT FLYOVER NOISE

Octave Frequency Band, cps	School and Motel Rooms: No. of Rooms	School and Motel Rooms: No. of Flyovers**	School and Motel Rooms: RMS Standard Dev.,* dB	Residential Rooms: No. of Rooms	Residential Rooms: No. of Flyovers**	Residential Rooms: RMS Standard Dev.,* dB
63	10	55	3.0	4	40	4.3
125	10	55	2.8	4	40	2.8
250	10	55	2.6	4	40	3.1
500	10	55	2.2	4	40	2.9
1000	10	54	2.2	4	40	2.7
2000	10	53	2.2	4	40	3.7
4000	7	34	3.5	4	38	3.2

* RMS value of the standard deviation computed for the individual rooms. Thus, if s_i is the noise reduction standard deviation for n_i flyovers in room i, then the rms value, $\langle s \rangle$, is:

$$\langle s \rangle = \left[\frac{\sum_{i=1}^{m} s_i^2}{m} \right]^{1/2}$$

where m= total number of rooms in which sets of noise reduction measurements were taken.

** Signal-to-noise limitations occasionally eliminated acquisition of satisfactory noise data at the higher frequencies.

TABLE II

REDUCTION OF AIRCRAFT NOISE OBSERVED IN FOUR RESIDENTIAL ROOMS

Type of Noise Signal	Room	No. of Measurements	Noise Reduction, PNdB	
			Mean Value	Standard Deviation
Takeoff	Living Room	39	20.9	3.4
	Bedroom	39	24.1	3.0
Approach	Living Room	46	22.1	2.6
	Bedroom	46	23.8	4.2

These standard deviation values indicate that the variability in measured noise reduction is generally considerably greater than the variability introduced by usual noise measurement errors. The values also indicate the relatively moderate precision with which the reduction of aircraft noise provided by a building can be specified. For example, based upon the rms value of the standard deviation for motel and school noise reduction measurements (3.7 PNdB for both propeller and jet aircraft flyovers), one would estimate that, for a large sampling of flyovers, 90 per cent of the noise reduction values would extend over a range of about 12 PNdB.

B. Noise Reduction Curves for Various Rooms

Figures 8 through 11 show noise reduction curves measured in different rooms. Each figure also has a cross-hatched band representing the approximate range of noise reduction values for light residential or commercial construction expected on the basis of the previous noise reduction studies of residential and air base buildings. The upper

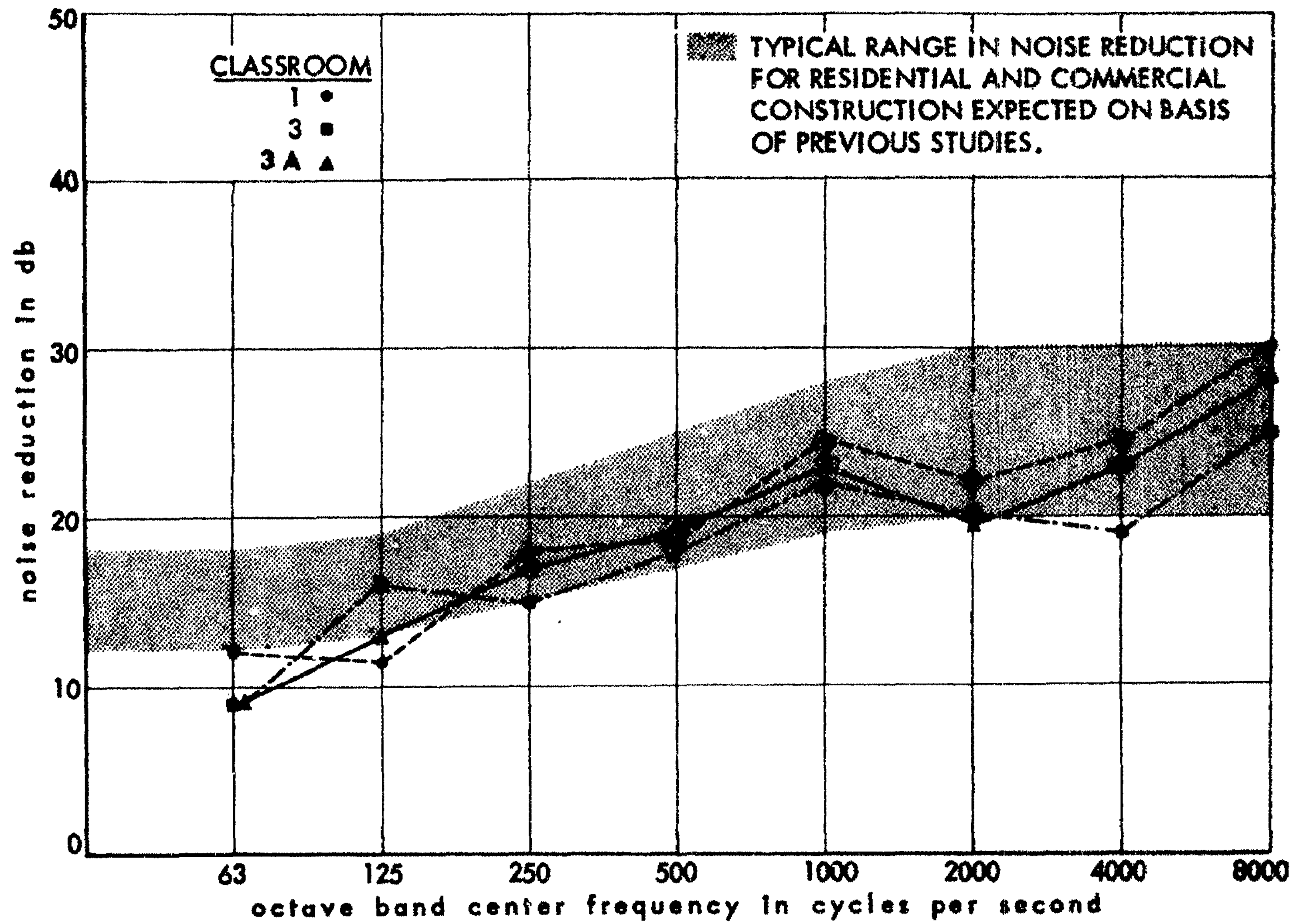


FIGURE 8. NOISE REDUCTION (MEDIAN VALUES) FOR JET AIRCRAFT FLYOVERS – APPROACH NOISE, THREE GRADE SCHOOL CLASSROOMS

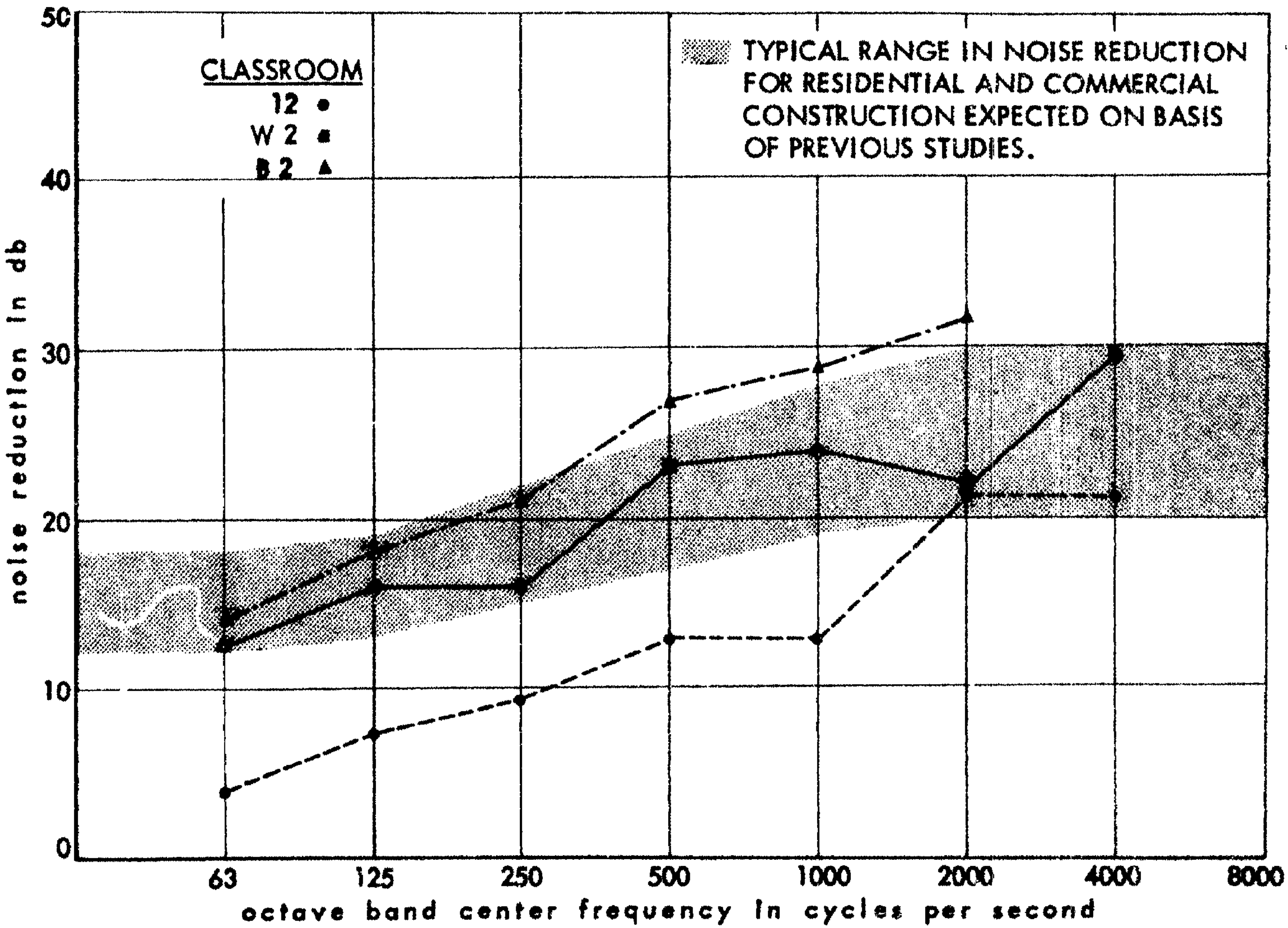


FIGURE 9. NOISE REDUCTION (MEDIAN VALUES) FOR JET AIRCRAFT FLYOVERS - APPROACH NOISE, THREE HIGH SCHOOL CLASSROOMS

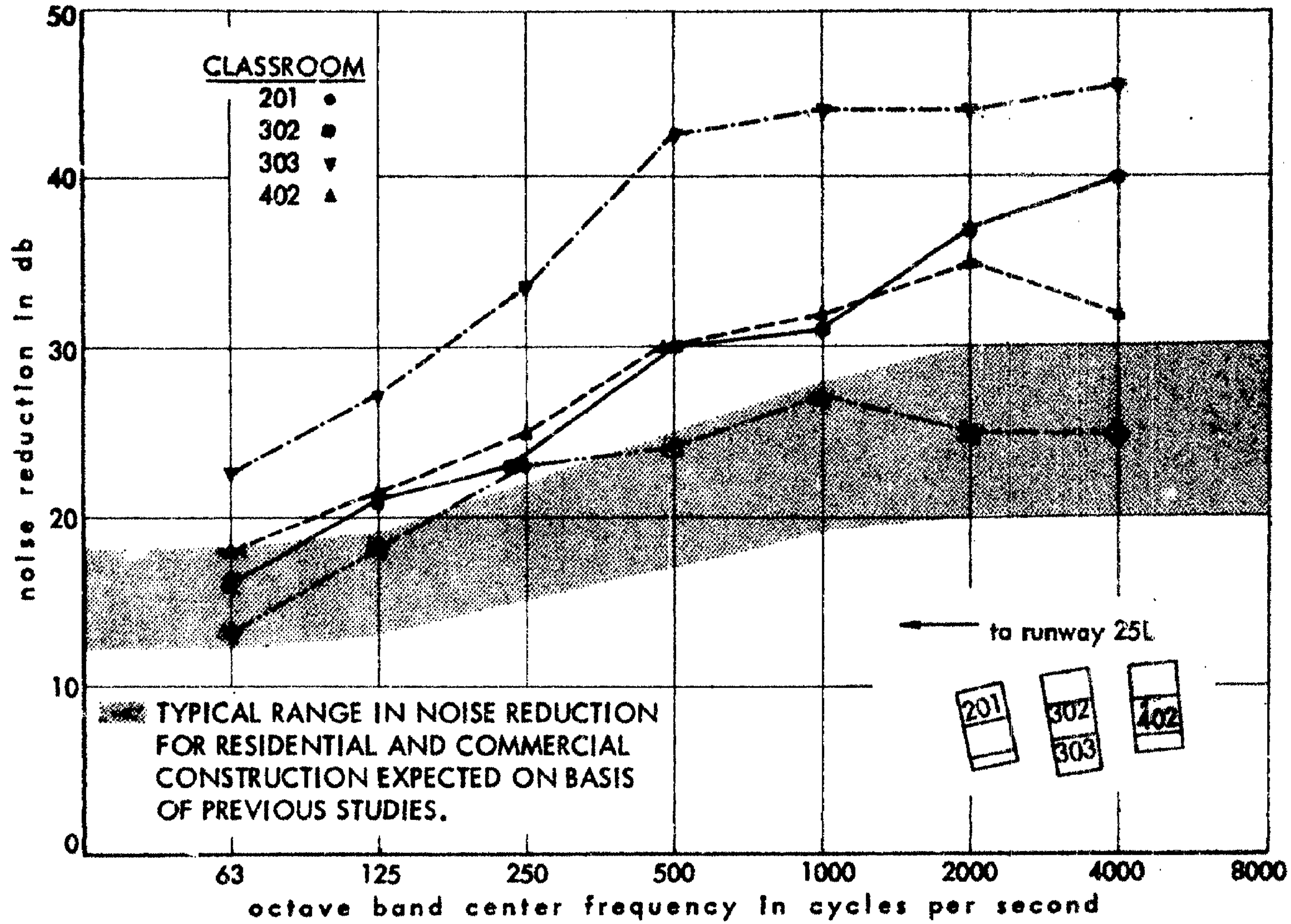


FIGURE 10. NOISE REDUCTION (MEDIAN VALUES) FOR JET AIRCRAFT TAKEOFFS - FOUR GRADE SCHOOL CLASSROOMS

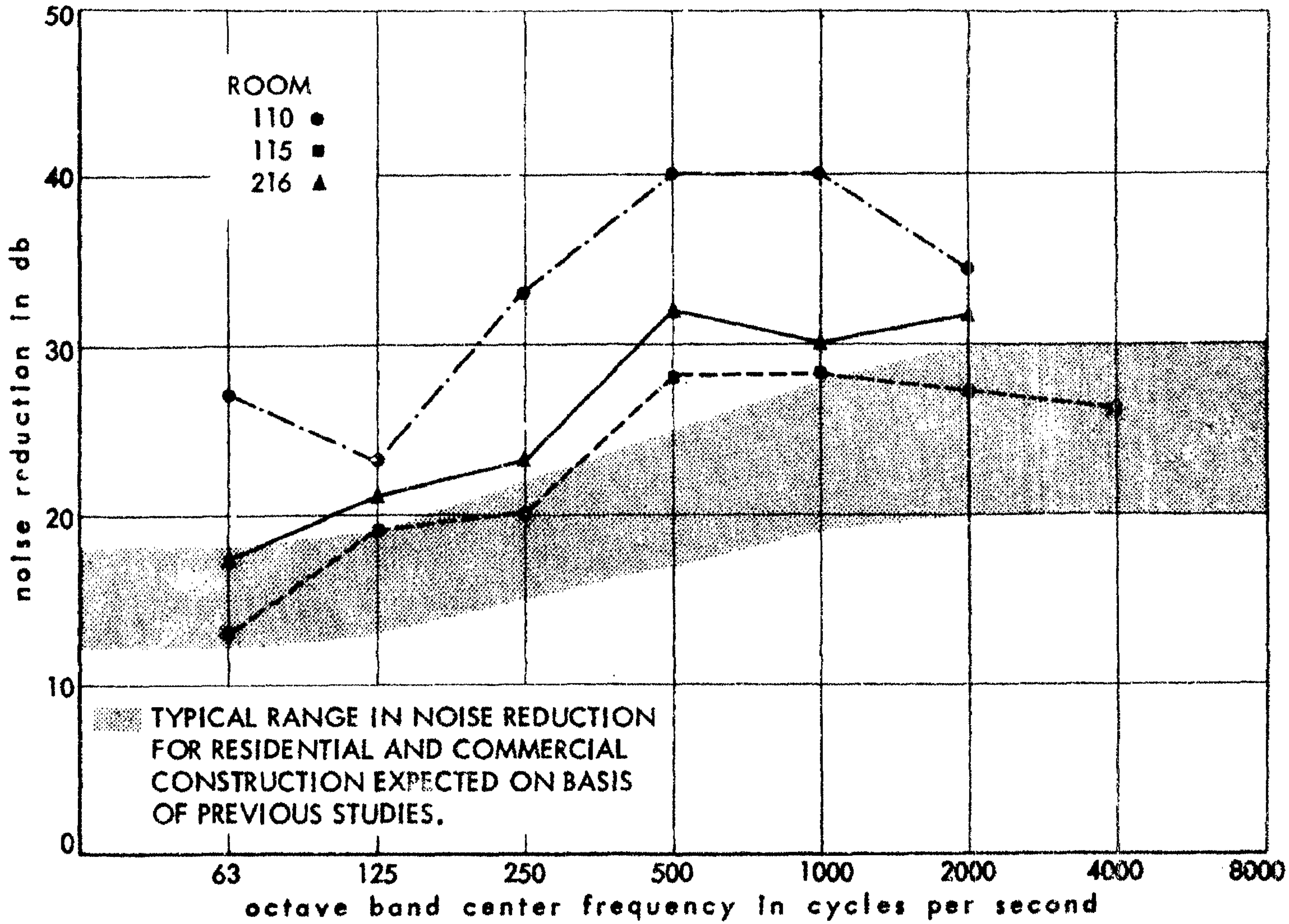


FIGURE 11. NOISE REDUCTION (MEDIAN VALUES) FOR JET AIRCRAFT FLYOVERS - APPROACH NOISE, THREE MOTEL ROOMS

limit of the shaded area represents the typical noise reduction expected for a house with windows closed; this upper limit also approximates the noise reduction for an air base office with 0.1% open area due to sound leakage paths around window frames and doors. The lower limit of the shaded area represents the typical noise reduction for a residential building with windows open.

Figure 8 shows median noise reduction values measured in three classrooms in a grade school under the approach path. The curves are quite similar, reflecting the similarity of the classroom design and construction, noise exposure and orientation with respect to the aircraft flight paths. Figure 9 shows noise reduction curves for three classrooms located in three different buildings of varying construction at a high school, also located under the approach path. Here, differences in the noise reduction of aircraft approach noise result primarily from differences in building construction.

Figure 10 shows the median noise reduction measured in each of four classrooms at a grade school located to one side of the takeoff path. Three of the rooms, Rooms 201, 302 and 402 were of similar construction. These rooms were each located in separate buildings which were approximately parallel to one another, as shown in the sketch. However, due to differences in terrain elevation, Rooms 302 and 402 were partially shielded from the takeoff noise by the building housing Room 201.

Comparison of the noise reduction measured in Rooms 302 and 303 is interesting since Room 303 represents a classroom specially soundproofed for aircraft noise. This room was located next to Room 302 with a common wall between rooms. In Room 302, each side wall (facing towards and away from the runway) contained large areas of single pane movable sash windows and doors without weatherstripping. In contrast, in Room 303, the sidewalls facing the runway was constructed of brick and had no windows or doors. The wall facing away from the runway contained double glazed windows and doors with

weatherstripping. Roof construction for Room 303 was substantially heavier than that for Room 302.

Comparison of the noise reduction values indicate that the soundproofing measures were moderately effective; the median noise reduction values increased from 31 PNdB in Room 302 to 37 PNdB in Room 303. (An increase in room noise reduction of 6 PNdB should result in a 25% reduction in loudness of flyovers heard inside the classroom).

Figure 11 shows the noise reduction for three rooms located in a motel near the approach path. The wall construction for all the rooms were the same, stucco on wood frame. The differences in noise reduction among the three rooms generally reflect different degrees of exposure to aircraft noise. Room 115 had only one wall directly exposed to aircraft noise, while in Room 216, the roof and one door were exposed to aircraft noise. Room 110, with only one exterior wall, showed increased noise reduction compared to Room 115 due to the partial shielding of flyover noise provided by an adjacent wing of the motel building.

As a final example of room noise reduction, Fig. 12 shows the median noise reduction for the four residential rooms measured. Each room had one (or two) exterior walls with windows which were directly exposed to aircraft noise.

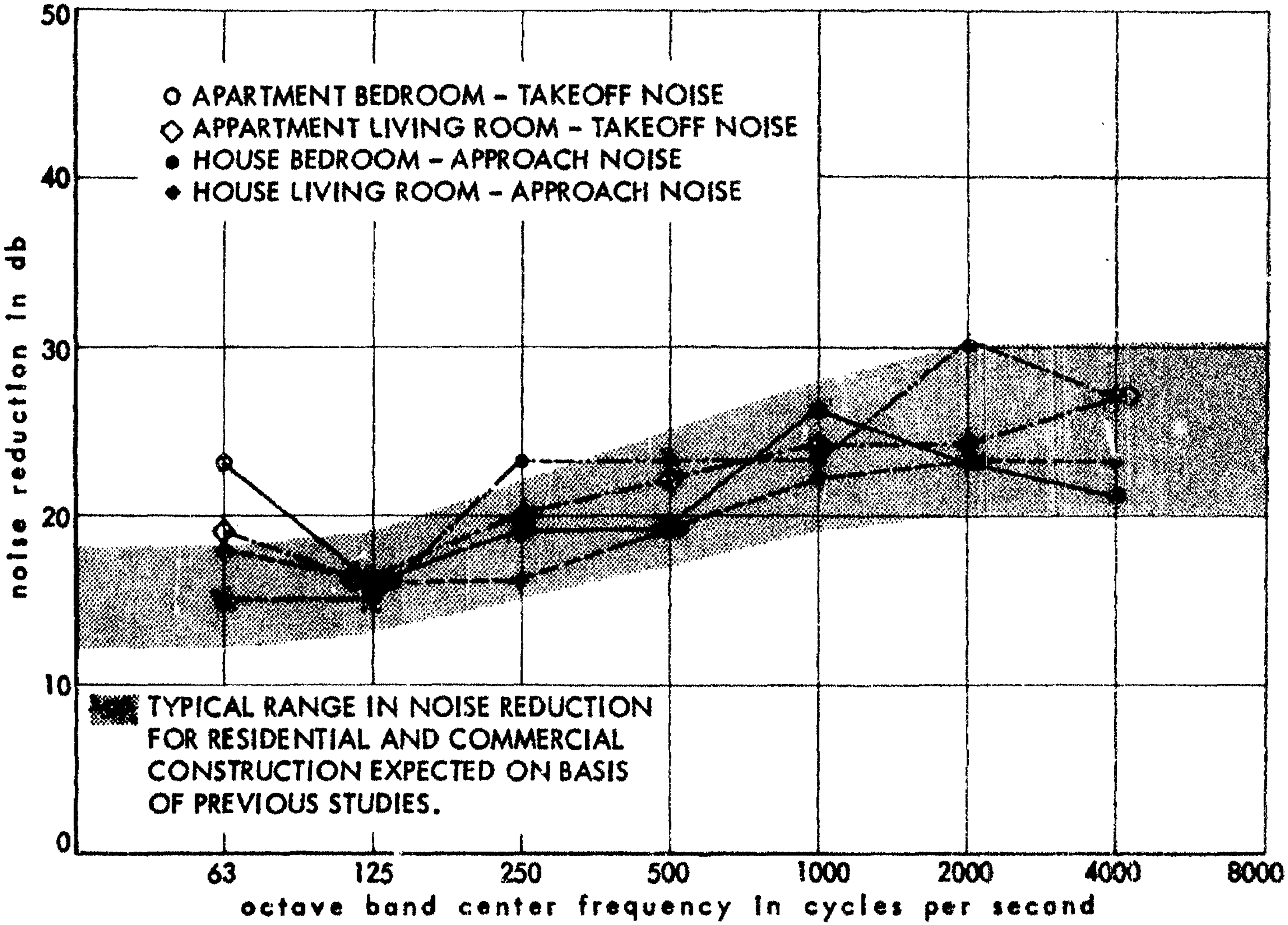


FIGURE 12. NOISE REDUCTION (MEDIAN VALUES) FOR JET AIRCRAFT FLYOVERS – FOUR RESIDENTIAL ROOMS

IV. SUMMARY AND CONCLUSIONS

Previous studies of the reduction of aircraft noise by buildings have shown that the noise reduction (exclusive of shielding) may be reasonably well estimated by taking into account noise transmission paths through (a) windows, (b) cracks and openings normally existing around windows and doors, (c) the basic wall and roof construction. In most conventional structures noise reduction is limited by the transmission of sound through windows and cracks; thus the noise reduction values measured in the field usually fall well below those which are calculated on the basis of basic wall or roof structures alone.

The present measurements generally confirm those findings. Although there is considerable variation in the detailed shape of the individual noise reduction curves, most of the noise reduction curves for rooms for which there was little or no shielding lie in or near the range of noise reduction values previously used as estimates of the noise reduction for conventional buildings of lightweight construction.

The one soundproofed classroom that was measured showed that a substantial increase in noise reduction could be achieved by limiting the amount of sound transmitted through (or around) doors and windows. The measurements also generally confirmed the fact that there is little or no benefit from specifying heavier construction for walls or the roof unless sound transmission paths through windows, doors, or other openings are carefully controlled.

As a measure of the variability in room noise reduction values, standard deviations were calculated for each set of noise reduction measurements made in individual rooms. For jet aircraft flyovers, the rms value of the standard deviations for the school and motel rooms was 2.7PNdB; for the four residential rooms, 3.4 PNdB. These relatively large standard deviation values illustrate both the relatively large variability in noise reduction which may be observed during successive aircraft flyovers, and the relatively moderate precision with which room (or building) reduction of aircraft noise can normally be specified.

REFERENCES

1. R. M. Hoover, A. C. Pietrasanta, "Some Measurements of Noise Reduction of Air Base Structures", WADC TN 58-243 (November 1958).

2. W. E. Clark, "Noise from Aircraft Operations", ASD TR 61-611 (November 1961).

3. D. E. Bishop, "Development of Aircraft Noise Compatibility Criteria for Varied Land Uses", Part II, FAA SRDS Report No. RD-64-148 (December 1964).

4. See Part II of this report, "Judgments of the Relative and Absolute Acceptability of Actual and Recorded Aircraft Noise".

5. BBN Technical Report, "Land Use Planning Relating to Aircraft Noise", FAA (October 1964). Also published by Department of Defense as AFM 86-5, TM 5-365, NAVDOCKS P-98, "Land Use Planning with Respect to Aircraft Noise".

6. K. D. Kryter, K. S. Pearsons, "Some Effects of Spectral Content and Duration on Perceived Noise Level", J. Acoust. Soc. Am., 35, 866-883 (1963).

7. K. D. Kryter, K. S. Pearsons, "Modification of Noy Tables", J. Acoust. Soc. Am., 36, 394-397 (1964).

8. K. D. Kryter, "The Meaning and Measurement of Perceived Noise Level", Noise Control, 6, 12-27, (September - October 1960).

FINAL REPORT

Contract No. FA-WA-4409

SRDS Report No. RD-65-130

Project 430-001-01R

PART V

COMPUTER-AIDED STUDY OF TIME PATTERNS OF NOISE FROM JET AIRCRAFT TAKEOFFS

December 1965

Prepared By

Dwight E. Bishop

Richard D. Horonjeff

BOLT BERANEK AND NEWMAN INC.
15808 Wyandotte Street
Van Nuys, California 91406

ABSTRACT

Computer techniques were employed to generate time histories of the perceived noise level at various ground positions under and adjacent to the aircraft flight path during simulated operations of jet and piston aircraft. The time durations of the noise signals, taken as the duration of the signal within 10 dB of the maximum level, were analyzed in terms of the aircraft speed and distance between aircraft and ground position. Time duration, perceived noise level and duration-modified perceived noise level charts are shown for simulated flyovers of turbojet, turbofan and piston aircraft at a constant altitude, and for simulated takeoffs of a large turbojet transport. Charts showing both perceived noise level and duration-modified perceived noise level contours for the takeoff of a large turbojet aircraft are also included.

For an aircraft flying at a constant speed and power setting, time duration was found to be a near-linear function of the ratio of slant distance to speed. However for the typical ranges of air speeds encountered during takeoff and climb, time duration may be correlated with slant distance (ignoring speed) with a typical spread in noise data of 2 to 3 duration-modified PNdB.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

I. INTRODUCTION

Most current methods for rating aircraft flyover noise depend upon the measurement of the maximum noise levels occurring during the flyover. Common practice is to measure the maximum noise levels occurring during the flyover in octave or third-octave frequency bands, then calculate the perceived noise levels from these data. The perceived noise level, so calculated, provides a measure of the relative noisiness or acceptability of the noise as heard by human observers.[1,2]

However, recent laboratory tests concerned with refining the perceived noise level scale have shown that the time duration of the signal also influences one's subjective rating of aircraft noise.[3]

For the relatively short time durations often encountered in aircraft flyover noise, the tests indicate that a doubling of signal duration increases the noisiness by an amount equivalent to about 4.5 PNdB. Thus, a more accurate indication of relative noisiness may be attained by using a duration-adjusted PNdB, or effective PNdB, defined as:

$$L_{eff} = L + 15 \log_{10} \frac{\Delta t}{t_{ref}} \qquad (1)$$

where:

L is the maximum perceived noise level during the flyover, expressed in PNdB

L_{eff} is the effective perceived noise level

Δt is the duration in seconds that the noise level exceeds a level 10 PNdB below the maximum perceived noise level

t_{ref} is a reference time duration, arbitrarily taken as 20 seconds in this report.

The study described in this report presents comparisons of the effective perceived noise level with the (unadjusted) perceived noise level for simulated level flight flyovers of turbojet, turbofan, and propeller transport aircraft, and for some simulated takeoffs of a turbojet transport aircraft.

This study forms a part of a larger program concerned with defining some of the variations encountered in measuring and describing aircraft noise in the vicinity of airports.* Computer-aided techniques for simulating aircraft flights were used extensively in the study. In essence, the computer generated and plotted time histories of perceived noise level at various ground positions under the aircraft flight path during the simulated operation of an aircraft.4/

The computer studies were made on a Digital Equipment Corporation computer, Model PDP-1. Information input to the computer was by means of typewriter or by transcribing graphical information using a special graphical input device. Graphical output was obtained from a paper-ink plotter.

Of the several variables determining the time duration of aircraft flyover noise signals, the effects of aircraft speed were emphasized in the study. Speed effects were explored for two reasons:

a) in many field investigations, information on aircraft speed or possible variations in speed is difficult to obtain. Thus, an understanding of the variability in time durations, and effective perceived noise levels introduced by typical speed variations, is helpful in interpreting field measurements.

b) an understanding of the effect of speed in determining signal duration will permit better evaluation of proposed tradeoffs in aircraft takeoff procedures. For example, a suggested change in procedures may require an evaluation of the subjective effects of a change in altitude versus a change in speed at various ground positions.

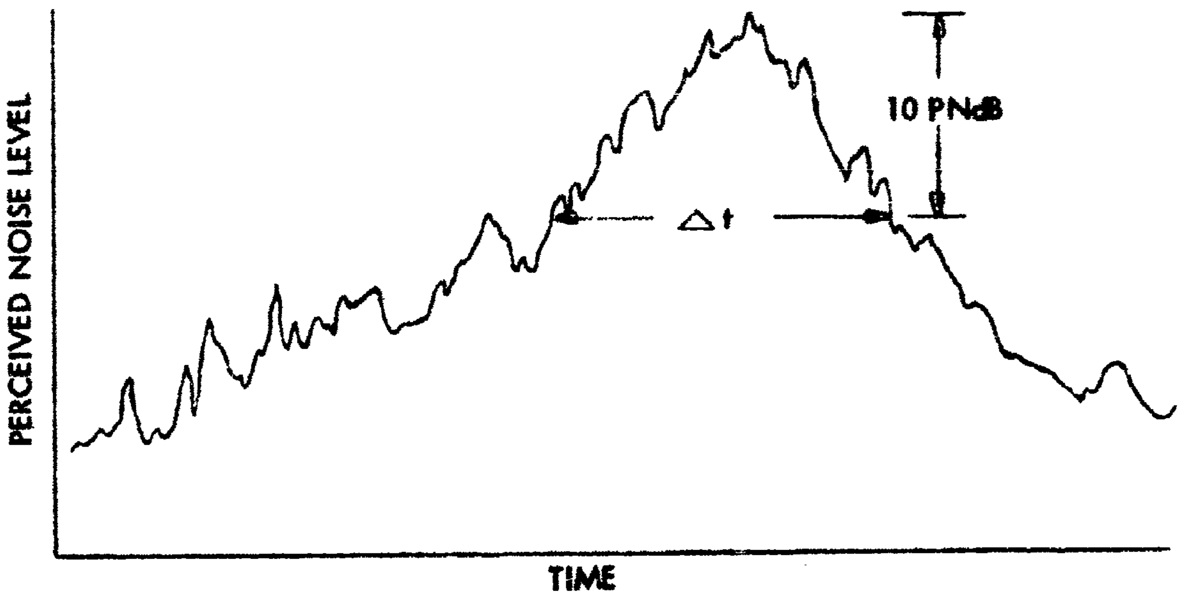
Section II discusses some of the parameters determining the time duration of aircraft noise signals. Succeeding sections of the report describe the analysis procedures employed, the results of the analysis, and conclusions.

---

* See Part IV and Part VI of this report.

II. DISCUSSION OF AIRCRAFT NOISE TIME PATTERNS

A typical time plot of the noise level observed below a jet aircraft flight path is sketched below:



Details of the shape of the noise plot may vary greatly from flyover to flyover. Because of such large variations in shape and because of the relative insensitivity of psychoacoustic judgments of noisiness or acceptability to details of the signal pattern, most descriptions of the time duration rely on relatively simple measurements of the time plots. A common measure of time duration that is used in both laboratory and field studies, and the one that will be used extensively throughout this report, is the number of seconds the noise signal is within 10 dB of the maximum value. This measure is

indicated in the sketch on the previous page.*

The detailed shape of the time patterns result from a number of variables. The four main parameters determining basic time pattern characteristics are:

a) the noise source characteristics of the aircraft

b) distance and geometrical relationships between aircraft and ground position

c) aircraft speed

d) atmospheric sound attenuation characteristics.

One way of visualizing the gross relationships between major parameters is shown in Fig. 1. In this figure, perceived noise level contours are drawn around a jet aircraft in flight. The shape and spacing of the contours is determined by the aircraft noise source characteristics, and the sound attenuation characteristics of the atmosphere.

In the figure we have assumed that the aircraft is flying in level flight. For altitude S_A, the maximum perceived noise level observed on the ground is 90 PNdB. The time duration is that determined by the ratio of the distance L_A divided by the aircraft speed. When the maximum noise level during the flyover is 95 PNdB, a smaller altitude S_B and a lesser distance L_B is indicated. Similarly, when the maximum noise level is increased to 100 PNdB,

---

* Another measure that has been used in some previous studies is the time duration of the pattern above a given reference noise level.4/ For example, the length of time that the signal exceeds 80 PNdB might be selected as a measure of signal duration.

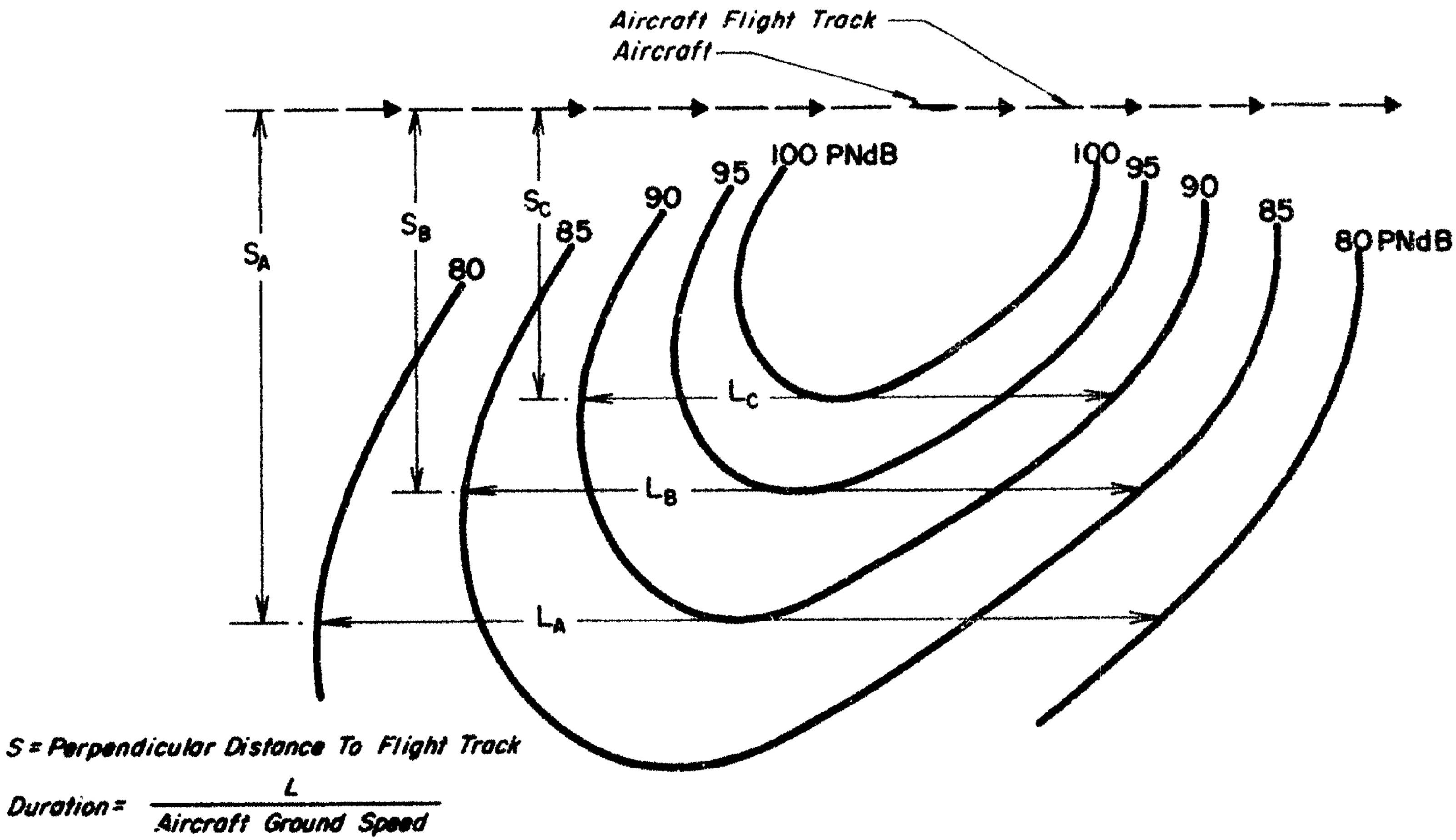


FIGURE 1. ILLUSTRATION OF NOISE CONTOUR AND DISTANCE RELATIONSHIPS FOR DETERMINING THE DURATION OF AN AIRCRAFT NOISE SIGNAL WITHIN 10 PNdB OF THE MAXIMUM FLYOVER NOISE LEVEL. (LEVEL FLIGHT FLYOVER).

a smaller altitude S_C and a lesser distance L_C are involved. With an increase in maximum noise level we see that the distance L and the altitude S decrease. We can also see from Fig. 1 that the time duration would vary inversely with the aircraft speed, since the distance L is divided by aircraft speed to obtain the duration.

In practice, of course, interpretations of time patterns are complicated by such factors as changing aircraft speed and altitude during the flyover, changes in engine power settings during the flyover, and spectrum changes introduced by Doppler shifts. Winds and varying air attenuation characteristics also cause distortion and fluctuations in the noise signals received on the ground.

Investigation of time patterns solely by analysis of field measurements introduces major experimental difficulties in separating and controlling different variables. Simulation of aircraft flights and generation of time patterns by a computer which allows major parameters to be independently controlled offers a convenient means for detailed study of some of the basic variables determining time patterns. The computer program and analysis procedures employed in this simulation are discussed in the following section.

III. ANALYSIS PROCEDURE

Time patterns for different ground positions, under and to one side of an aircraft flight path, were generated using computer techniques to simulate aircraft flyovers. Input information consisted of: aircraft flight track over ground; aircraft altitude profile; aircraft airspeed profile*; air attenuation (standard SAE values)5/; and noise spectra, defined at a constant radius about the aircraft at 10° intervals. The above information was entered in the computer by either graphical or tabular means.

The output of the computer program consisted of time histories of the perceived noise level for specified ground positions. The maximum perceived noise level reaching the ground positions was determined to the nearest 0.5 PNdB for every 1000 ft interval along the flight path. The time of arrival of the maximum noise signal for each 1000 ft interval was then determined and plotted to the nearest 0.5 second. Typical computer plotted graphs are shown in Figs. 2 and 3.

The maximum perceived noise level and time duration were read from each time history. These values, together with the slant distance between ground position and aircraft flight track, also obtained from the computer program, constitute the basic data for our study.

A straight flight track over the ground was assumed throughout the study. Initially, we simulated flyovers of aircraft at a constant altitude of 1000 ft and at constant speeds of 300 ft per second (178 knots) for

---

* Actually, the horizontal component of the airspeed. Although the computer program has provision for introducing wind effects, the studies were confined to zero-wind conditions; hence, aircraft airspeed and ground speed are identical, and will be referred to simply as aircraft speed.

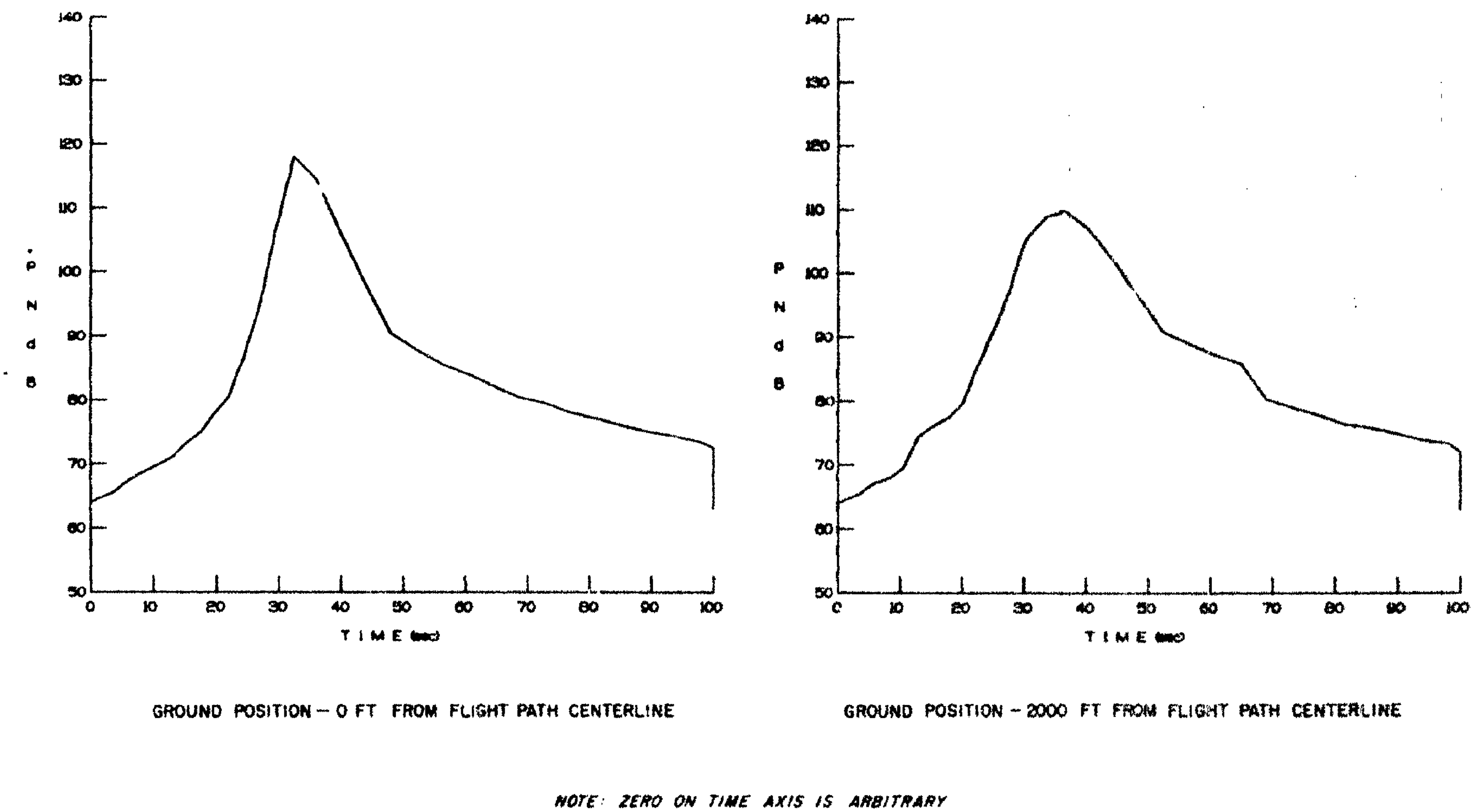
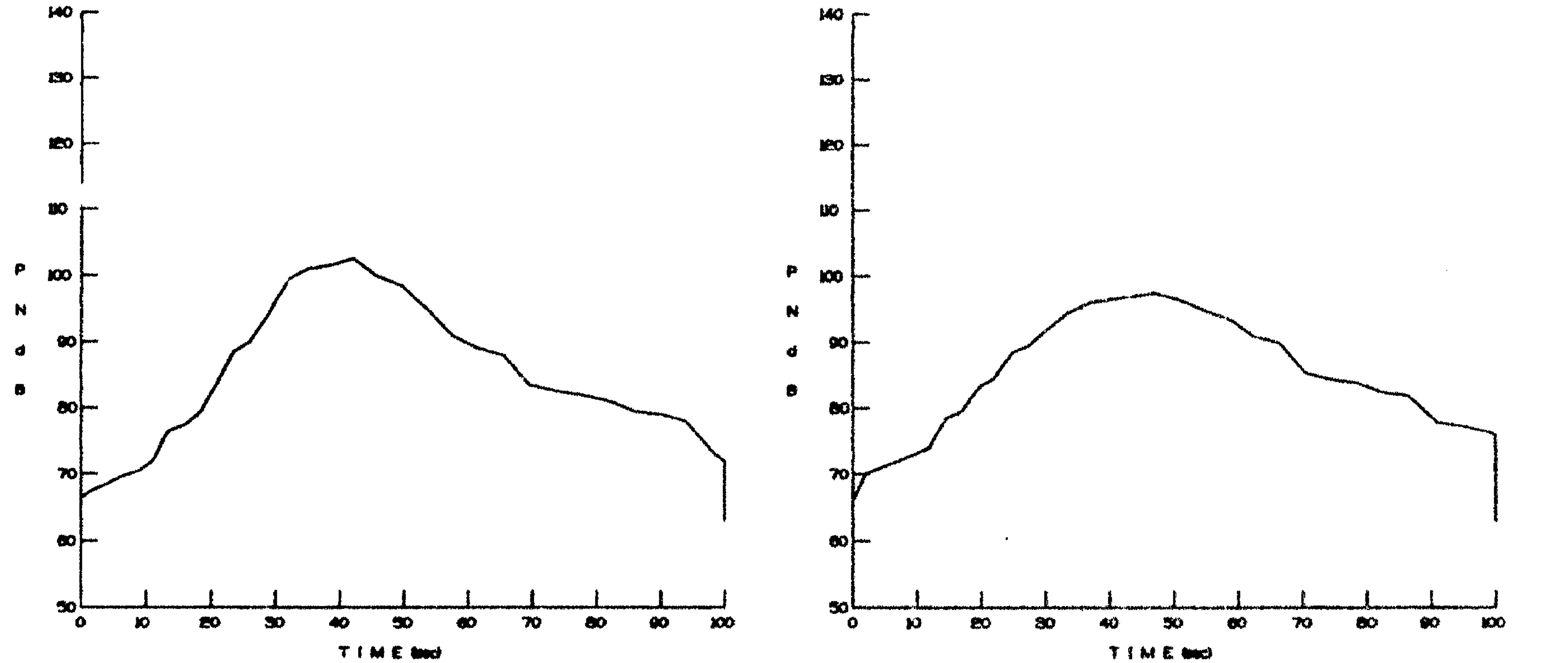


FIGURE 2. TYPICAL TIME HISTORIES PLOTTED BY COMPUTER — LARGE TURBOJET AIRCRAFT FLYOVER AT 1000 FT ALTITUDE, 300 FT PER SECOND SPEED.



GROUND POSITION – 4000 FT FROM FLIGHT PATH CENTERLINE

GROUND POSITION – 6000 FT FROM FLIGHT PATH CENTERLINE

NOTE: ZERO ON TIME AXIS IS ARBITRARY

FIGURE 3. TYPICAL TIME HISTORIES PLOTTED BY COMPUTER — LARGE TURBOJET AIRCRAFT FLYOVER AT 1000 FT ALTITUDE, 300 FT PER SECOND SPEED.

jet aircraft and 250 fps (148 knots) for propeller aircraft. Simulated flyovers of a large turbojet transport aircraft, a large turbofan transport aircraft, a Boeing 727, and a large piston transport aircraft were made at these constant altitude and speed conditions.

Time patterns were calculated for six ground positions located directly underneath the flight path and at distances 1000, 2000, 4000, 6000, and 8000 ft to one side of the flight track. Figures 2 and 3 show the resulting time histories for four ground positions for the simulated flyover of a large turbojet transport aircraft.

In the second phase of the study, takeoffs of a large turbojet transport aircraft were simulated. The altitude profile employed, shown in Fig. 4, is typical of that for a large, long range jet transport.6/

Several different speed profiles were employed; these are shown as curves A, B and C in the lower portion of Fig. 4. They were selected to bracket the range of speeds likely to be encountered for large turbojet and turbofan aircraft takeoffs. However, they do not portray in detail the characteristics of any specific aircraft.

For each simulated takeoff, time histories were computed at 16 ground positions. These positions were located directly underneath the flight path and 2000, 4000 and 8000 ft to one side of the flight track at distances of 10,000, 15,000, 25,000 and 35,000 ft from the start of takeoff roll.

The noise spectra for the simulation studies were, with the exception of the Boeing 727, generalized spectra developed from comparison of the noise spectra of a number of current transport aircraft. These spectra, together with the Boeing 727 spectrum, are shown in Fig. 5. The noise levels are the maximum to be observed at a distance of 1000 ft from the aircraft during a flyover.

Information or the in-flight directional characteristics of noise radiated by jet or propeller aircraft is rather

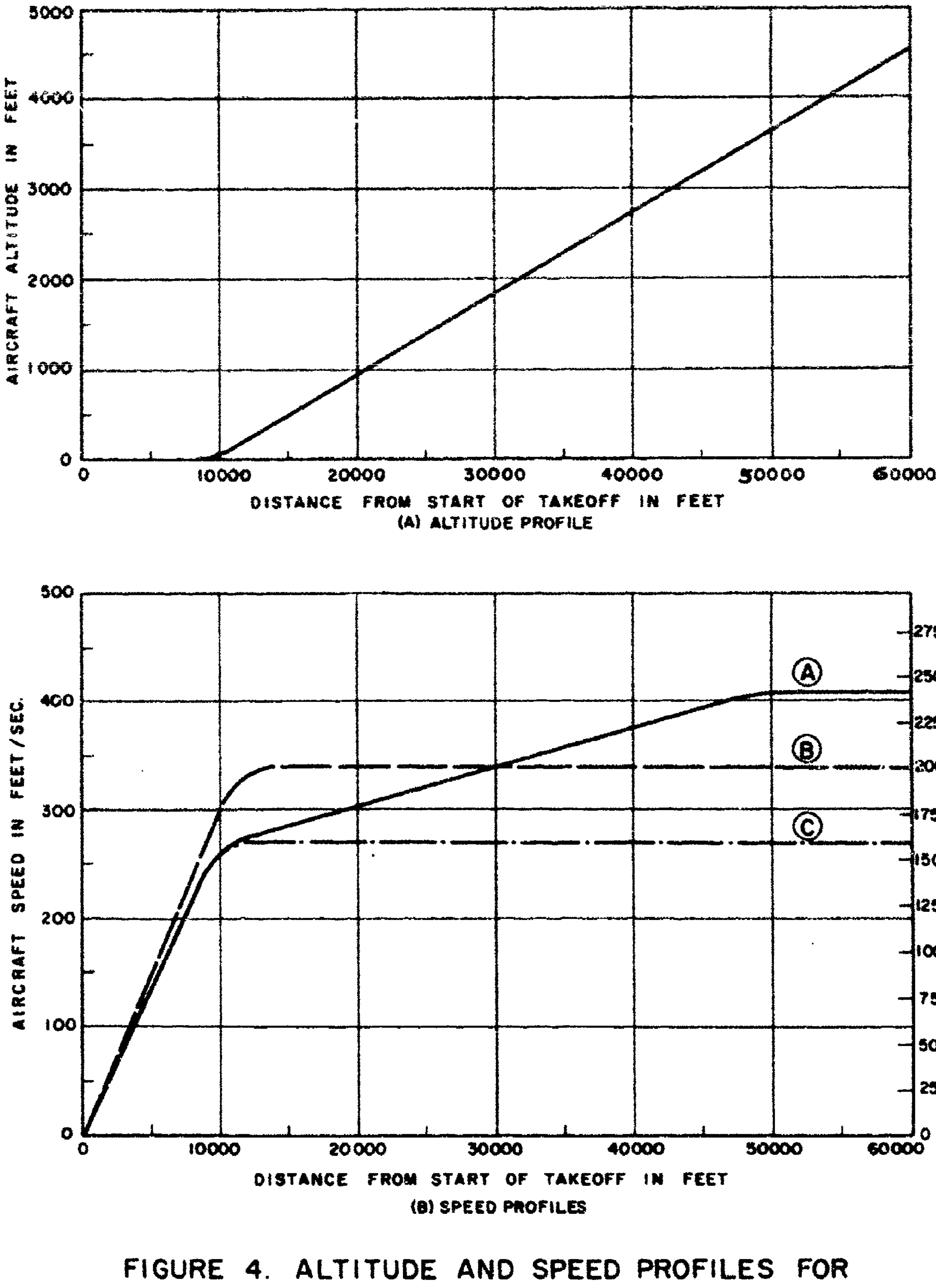


FIGURE 4. ALTITUDE AND SPEED PROFILES FOR SIMULATED TURBOJET AIRCRAFT TAKEOFFS.

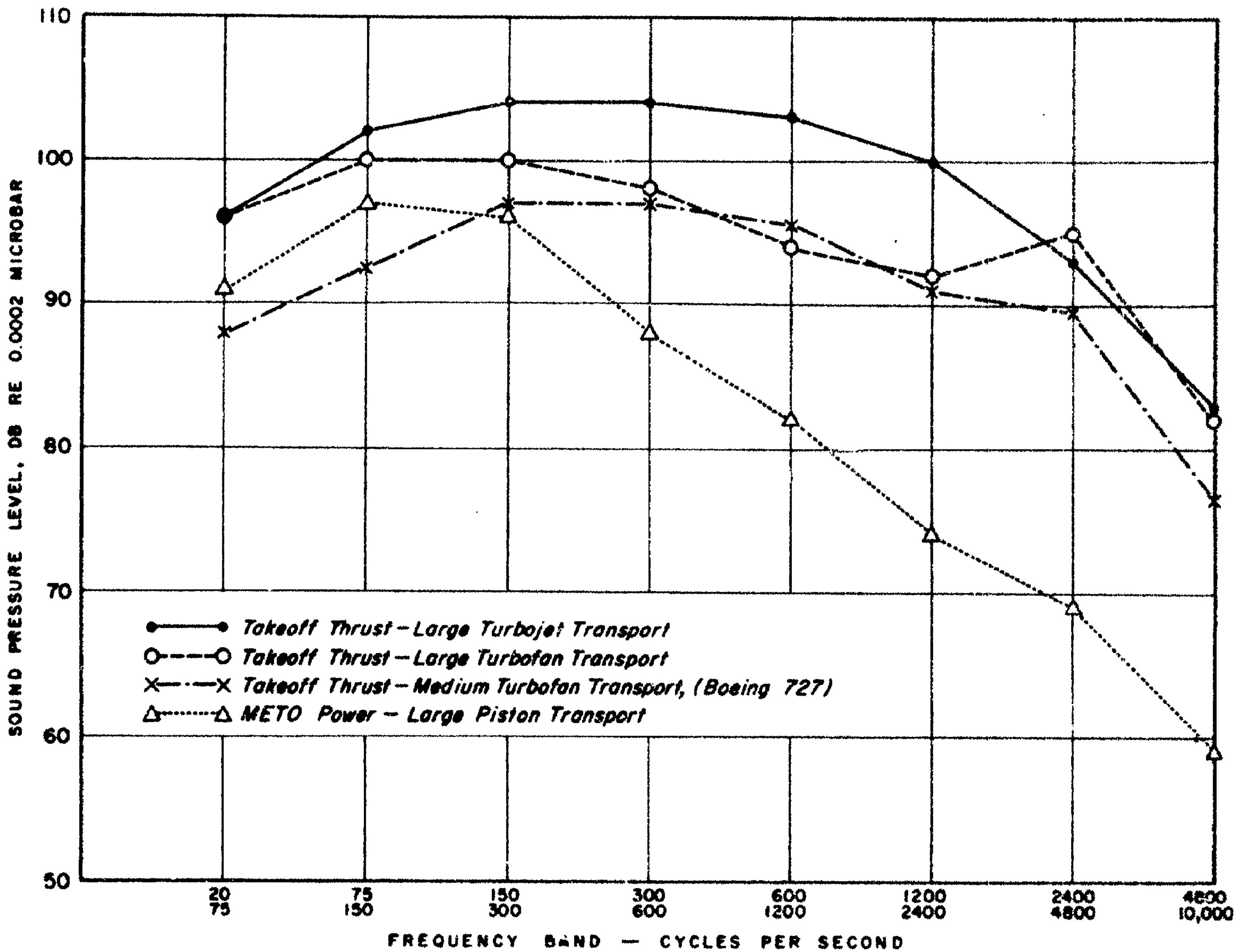


FIGURE 5. AIRCRAFT NOISE SPECTRA FOR SIMULATED FLYOVERS – (MAXIMUM LEVELS AT A POINT 1000 FT. FROM FLIGHT TRACK).

limited. Although numerous measurements of the directional characteristics of jet engines during ground runup operations are available, the noise radiation from engines in flight may be considerably different from that observed during ground runups. As a consequence, the directional characteristics employed for the flight simulations (other than for the Boeing 727) are estimates, derived from study of the rather limited data available. For the Boeing 727, detailed noise information was available,7/ giving octave-band spectra at 10° intervals, based on analysis of actual flyover noise measurements.

The directivity patterns used in the simulations are given in Table I. The directivity patterns are stated in dB with reference to the noise levels at the angle of maximum radiation. For all but the Boeing 727, noise levels in each octave band were changed in accordance with the directivity characteristics shown in the table. This, of course, is an approximation since directivity patterns will vary in the different octave frequency bands. The 727 directivity pattern, interpreted in PNdB at a 1000-ft radius, is also listed in Table I. It should be noted that the values shown in the table for the Boeing 727 do not necessarily indicate the directivity pattern in the individual octave frequency bands.

Initially, a uniform directional pattern was assumed for the propeller aircraft. However, this pattern produced time durations that were unrealistically large compared with available field data.8/ As a consequence, a non-uniform directional pattern, based upon known propeller noise characteristics, was assumed. This pattern provides values of time duration which agree well with field data.

TABLE I

AIRCRAFT NOISE DIRECTIVITY PATTERNS AT 1000 FT
FOR SIMULATED AIRCRAFT FLYOVERS

Angle from Nose, degrees	AIRCRAFT TYPE			
	(A) Large Turbojet Transport, dB	(B) Large Turbofan Transport, dB	(C) Boeing 727, PNdB	(D) Large Piston Transport, dB
0	--	--	--	--
10	-23	-20	--	-5
20	-20	-17	-15	-5
30	-17	-14	-14	-4
40	-14	-11	-11	-4
50	-11	- 8	- 9	-3
60	- 8	- 6	- 7	-2
70	- 6	- 4	- 4	-1
80	- 4	- 3	- 2.5	-1
90	- 3	- 2	- 1.0	0
100	- 2	- 1	- 1.0	0
110	- 1	0	- 1.0	0
120	0	- 1	- 0.5	0
130	- 1	- 3	0	-1
140	- 3	- 6	- 2.0	-3
150	- 6	- 9	- 6.0	-4
160	- 9	-13	--	-4
170	-13	-17	--	-5
180	--	--	--	--

For (A), (B), and (D), all octave bands were shifted uniformly by the amounts shown. Noise levels for (C), the Boeing 727, changed in relative spectrum shape as well as level at different angles. Thus, the values for (C) show the relative directivity in PNdB along a 1000-ft radius and do not necessarily correspond to the directivity pattern in the individual octave bands.

IV. TIME PATTERNS AT CONSTANT ALTITUDES AND SPEEDS

Figure 6 shows, as a function of slant distance, the time durations for simulated flyovers of the four different aircraft at constant altitude and speeds. The plotted points generally form quite smooth straight lines. The lines have slopes approximately equal to 1.0, thereby indicating a near-linear relationship between slant distance and duration. The time durations for the three jet aircraft flyovers are all significantly shorter than the time duration for the piston aircraft. This difference in duration between jet and piston aircraft is greater than can be accounted for by the difference in aircraft speeds and reflects differences in directivity patterns between the jet and piston aircraft.

Figure 7 shows, for the same simulated flyovers, plots of the perceived noise level versus distance for the four aircraft. Figure 8 shows the effective perceived noise level based upon the maximum perceived noise levels of Fig. 7 and the time durations of Fig. 6, modified in accordance with Equation 1.*

---

* Laboratory explorations of the effect of time duration on subjective ratings of aircraft noise were confined to signals of relatively short duration (12 seconds or less).3/ One might expect that for larger time durations, perhaps of the order of 30 seconds or more, noisiness judgments would become independant of the time duration. However, in this report we have not limited application of Equation 1 to any specific time interval, or maximum duration, since our major purpose is to demonstrate the dependance of signal time duration upon various physical parameters.

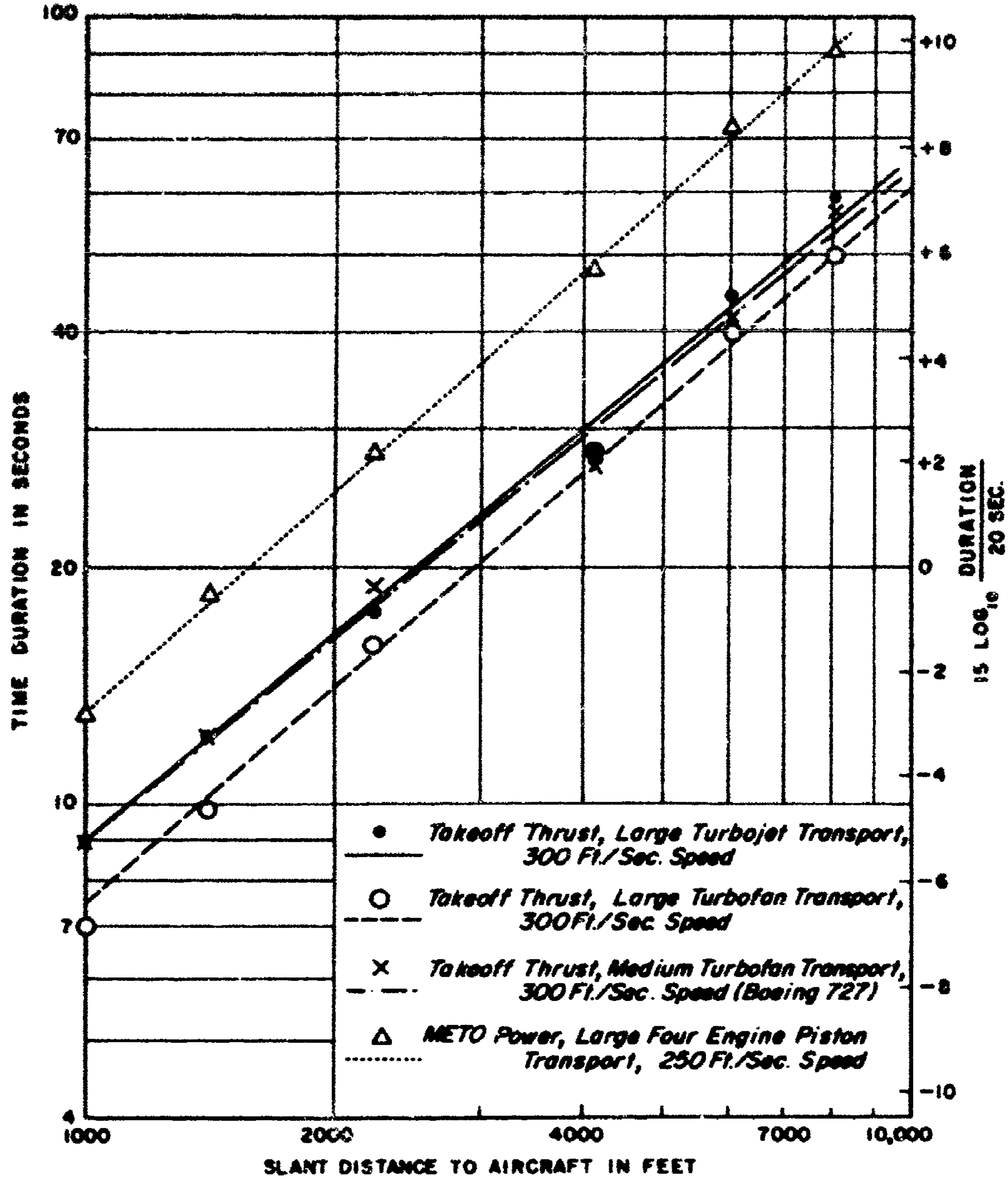


FIGURE 6. VARIATION OF AIRCRAFT NOISE DURATION WITH SLANT DISTANCE — SIMULATED AIRCRAFT FLIGHTS AT 1000 FT. ALTITUDE AND CONSTANT GROUND SPEED.

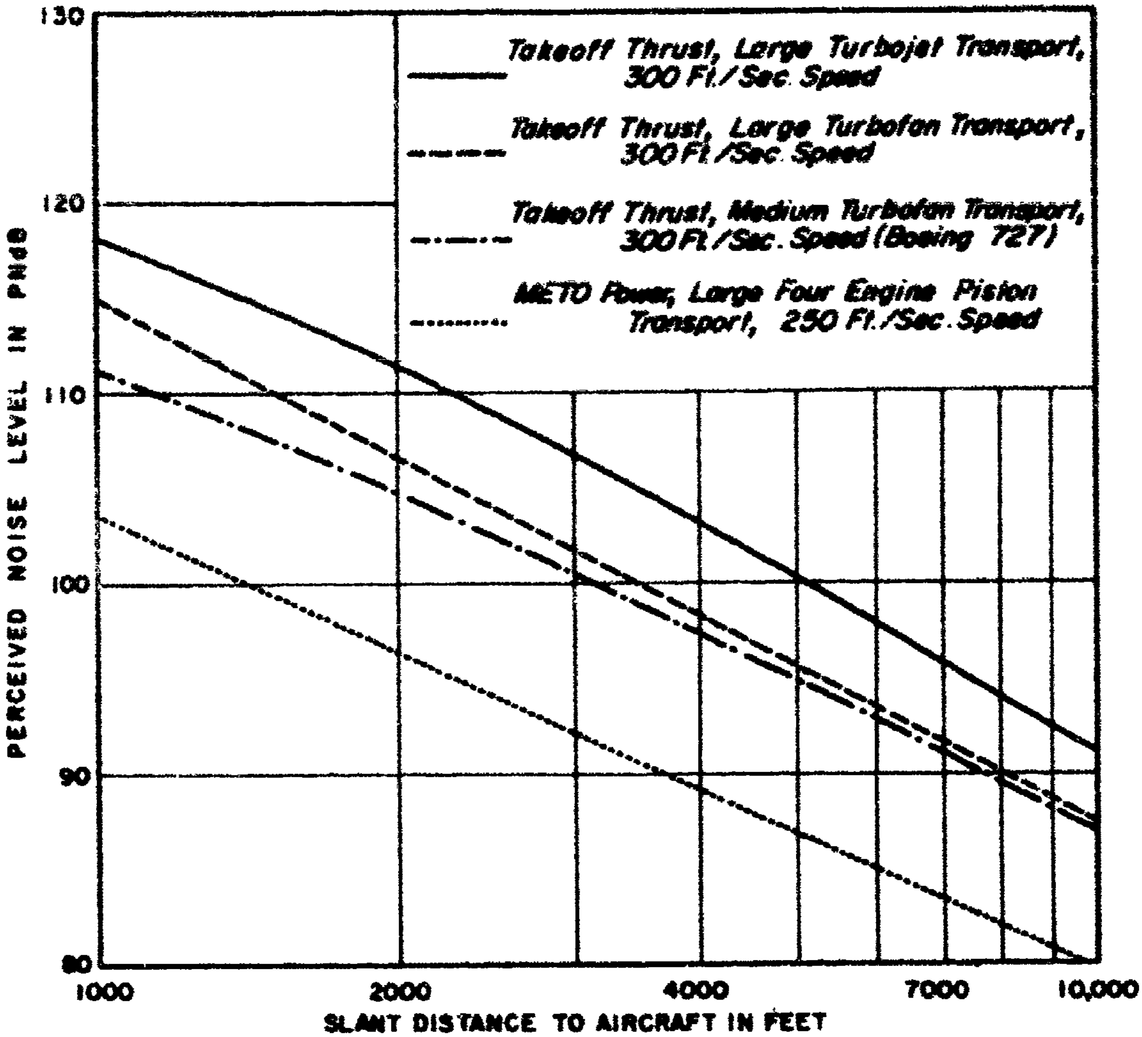


FIGURE 7. VARIATION OF PERCEIVED NOISE LEVELS WITH SLANT DISTANCE — SIMULATED AIRCRAFT FLIGHTS AT 1000 FT. ALTITUDE AND CONSTANT SPEED.

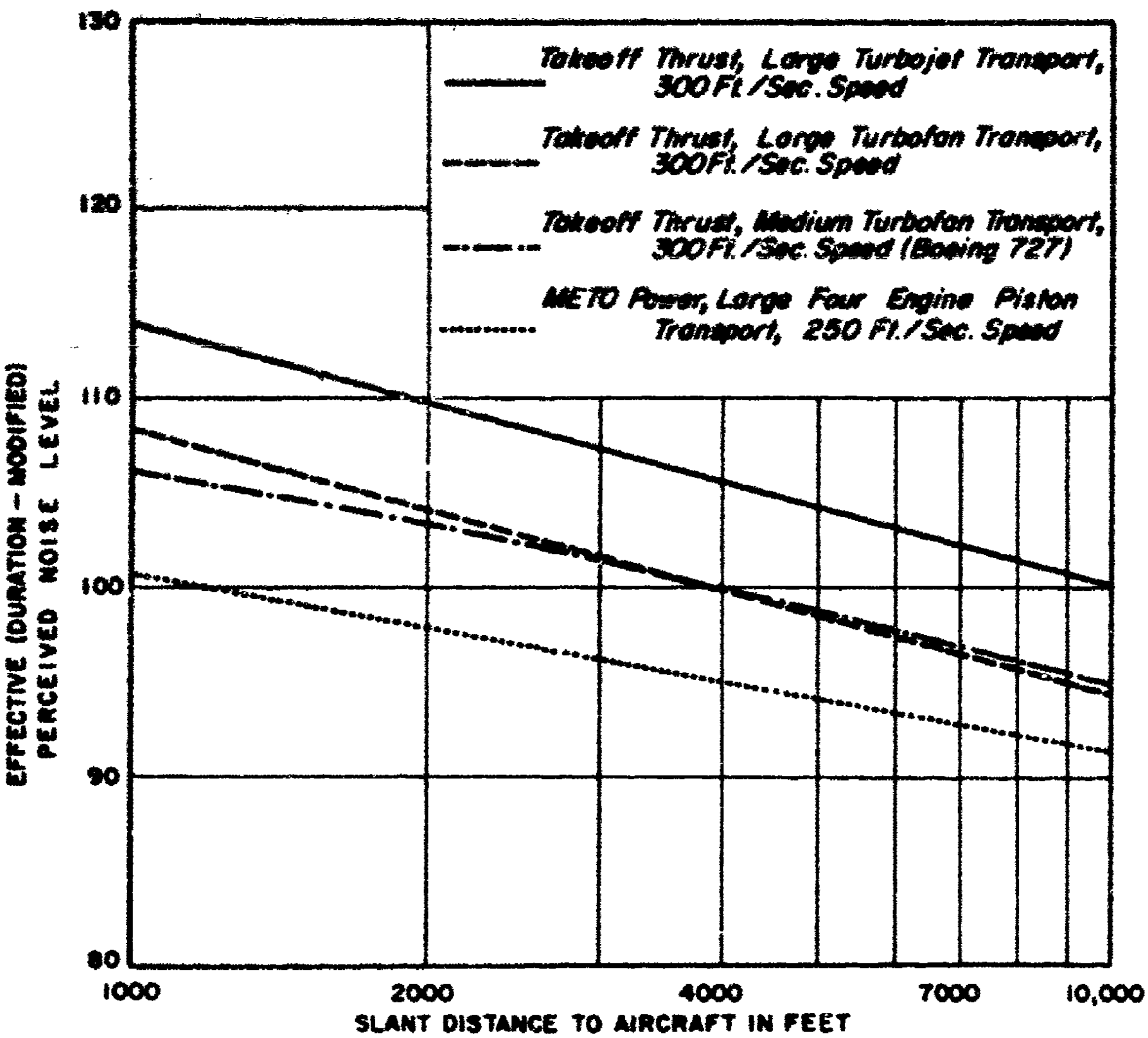


FIGURE 8. VARIATION OF EFFECTIVE DURATION—MODIFIED PERCEIVED NOISE LEVELS WITH SLANT DISTANCE—SIMULATED AIRCRAFT FLIGHTS AT 1000 FT. ALTITUDE AND CONSTANT SPEED

Comparison of Figs. 7 and 8 shows that:

a) the differences in noise levels between jet and piston aircraft is less for effective perceived noise levels than for the unmodified perceived noise levels. This, of course, is a consequence of the relatively longer duration of signals for the piston aircraft.

b) the slopes of the curves relating the effective perceived noise level with distance are much less than the slopes of the curves relating unmodified perceived noise levels with distance.

For example, the curve for turbojet aircraft in Fig. 8, shows an average decrease of about 4.5 PNdB (effective) per doubling of distance, instead of about 8 PNdB for unmodified perceived noise levels.

V. TIME PATTERNS FOR VARYING ALTITUDE AND SPEED PROFILES

Figure 9 shows the time durations of noise signals plotted as a function of distance from aircraft to ground position for three simulated takeoffs of a large turbojet transport. The takeoffs employed the three different speed profiles and the single altitude profile of Fig. 4. Durations for the three different speed profiles are identified in the figure. The shaded area indicates the approximate spread in duration values. For a given slant distance we note that the time durations typically varied by a ratio of about 1.5 to 1.

If we interpret the time durations shown in Fig. 9 in terms of effective perceived noise level (in accordance with Equation 1) we obtain the band of effective perceived noise levels shown in Fig. 10. Also shown in this figure is the unmodified perceived noise level curve. For a given slant distance, the variation in duration has resulted in a spread in effective perceived noise levels of 2 to 3 PNdB.

In many field investigations of aircraft noise, the particular speed at which the aircraft was flown, or the extent of speed changes during the course of the flyover, are unknown. In such cases, correlations of time durations, or effective perceived noise levels with distance, as illustrated in Figs. 9 and 10 represent a practical limit in analysis. However, when speed information is available, the band of duration values shown in Fig. 9 can be substantially reduced by plotting the data in terms of the ratio of distance to speed as shown in Fig. 11. In plotting this graph, the speed was taken to be that existing at the time the aircraft was nearest the observation point. For a number of positions, particularly for those located only 10,000 ft from the start of takeoff roll, aircraft speed was changing for a significant portion of the time history. These speed variations during the flyover account for some of the "residual" spread of values shown in Fig. 11.

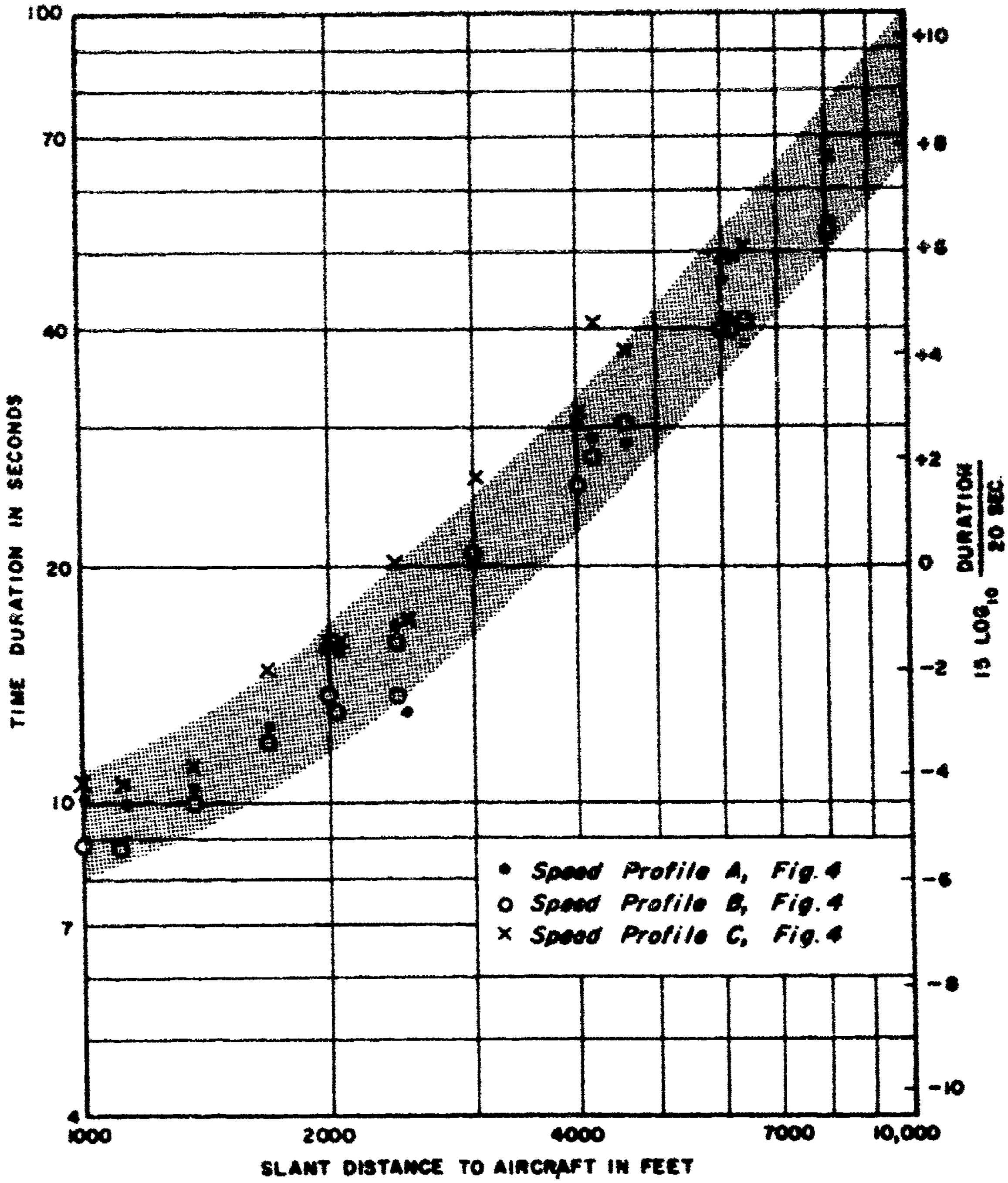


FIGURE 9. VARIATION OF AIRCRAFT NOISE DURATION WITH DISTANCE — SIMULATED TAKEOFFS OF A LARGE TURBOJET TRANSPORT AIRCRAFT WITH VARYING SPEED PROFILES.

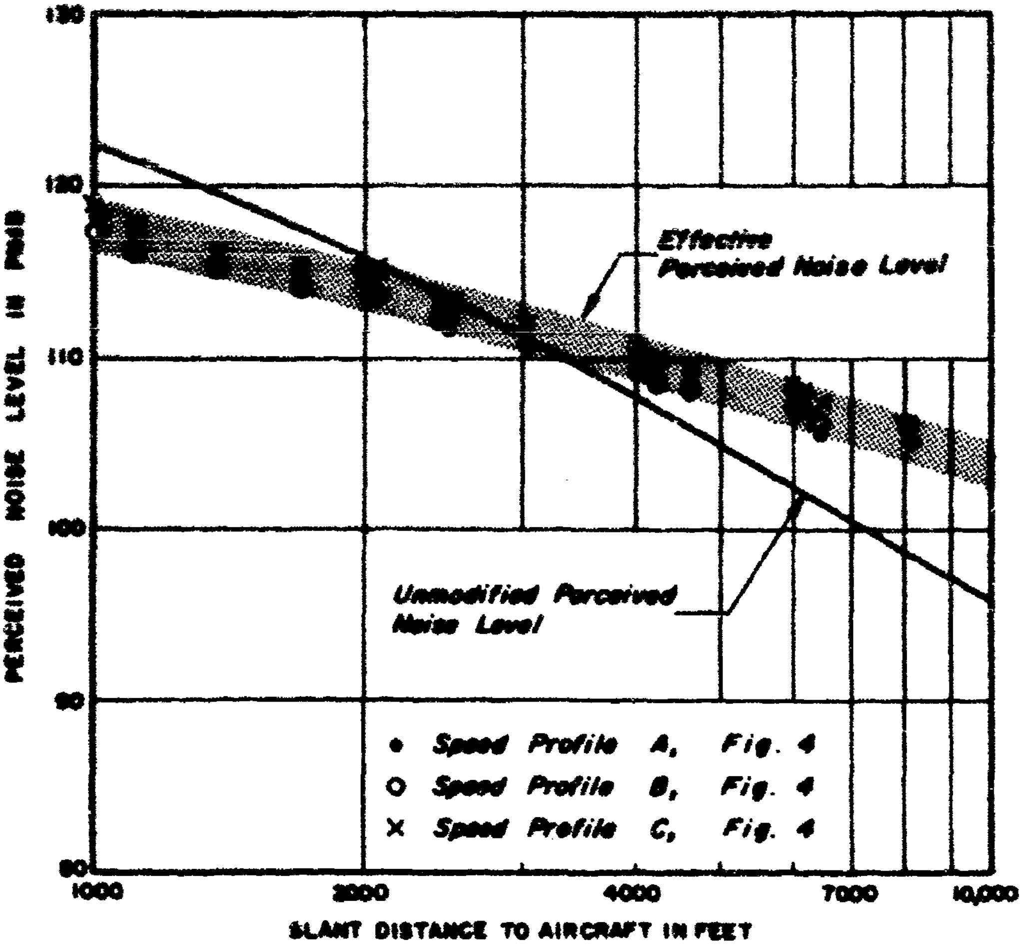


FIGURE 10. VARIATION OF EFFECTIVE (DURATION—MODIFIED) AND UNMODIFIED PERCEIVED NOISE LEVELS WITH DISTANCE —SIMULATED TURBOJET AIRCRAFT TAKEOFF WITH DIFFERENT SPEED PROFILES.

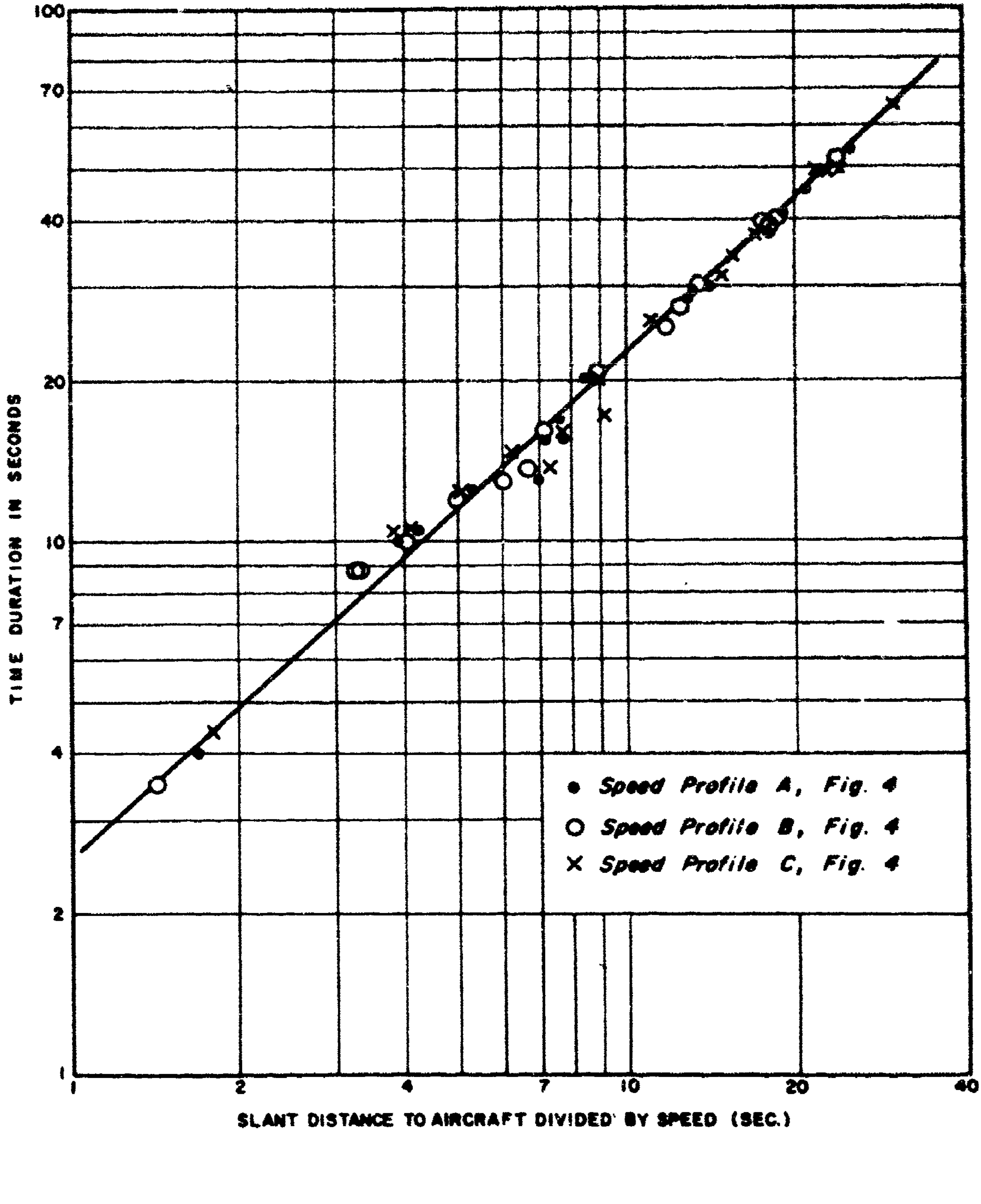


FIGURE 11. VARIATION OF AIRCRAFT NOISE DURATION WITH RATIO OF ALTITUDE TO SPEED — SIMULATED TAKEOFFS OF A LARGE TURBOJET TRANSPORT AIRCRAFT.

Figure 11, and the unmodified perceived noise level curve in Fig. 10, can be used to estimate changes in duration or effective perceived noise levels for various speed and altitude tradeoffs. As an example, let us consider the noise levels directly under the aircraft flight path during a flyover at an altitude of 1200 ft and a speed of 180 knots (304 fps). We wish to evaluate the effects of an increase in air speed to 220 knots (372 fps). At a distance of 1200 ft, the ratios of distance to speed for the air speeds of 180 knots and 220 knots are 3.95 and 3.23 respectively. Using these two quantities to enter Fig. 11, we can determine that the time duration of the flyover signals is 9.1 seconds at 180 knots and 7.6 seconds at 220 knots. By use of Equation 1 (Page 1) this reduction in time duration with an increase in air speed is found to decrease the effective perceived noise level by approximately 1.2 PNdB.

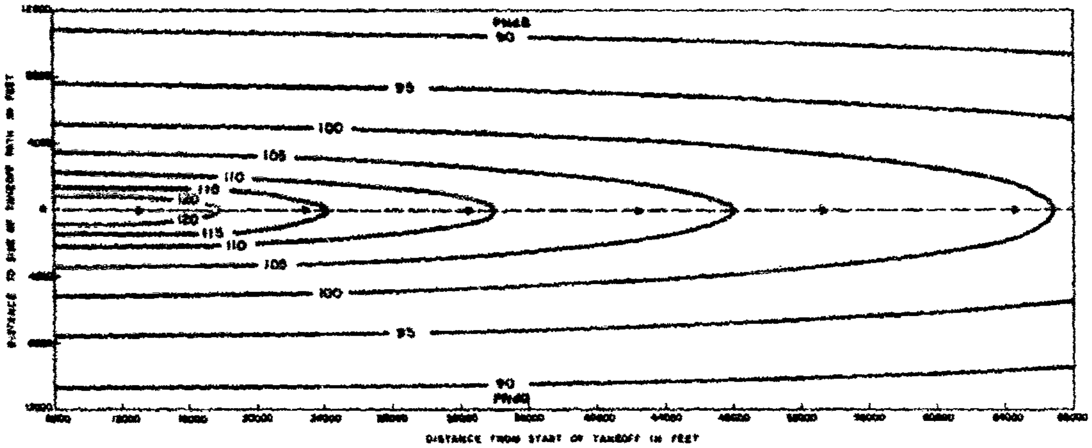
Now, from the unmodified perceived noise level curve in Fig. 10, one can determine that 1.2 PNdB is equivalent to a change in altitude of about 150 ft about the referenced altitude of 1200 ft. Therefore, if the increase in aircraft speed from 180 to 220 knots resulted in a reduction in aircraft altitude to less than about 1050 ft (1200 - 150) then the increase in aircraft speed would not result in a lower effective perceived noise level heard on the ground directly beneath the aircraft.

For positions to one side of the path, changes in noise levels due to altitude variations will be less than observed directly under the flight path. This is due to the fact that the relative changes in distance to the aircraft are less. However, changes in the effective perceived noise level resulting from speed changes will be equally effective at positions to one side or directly under the flight path.

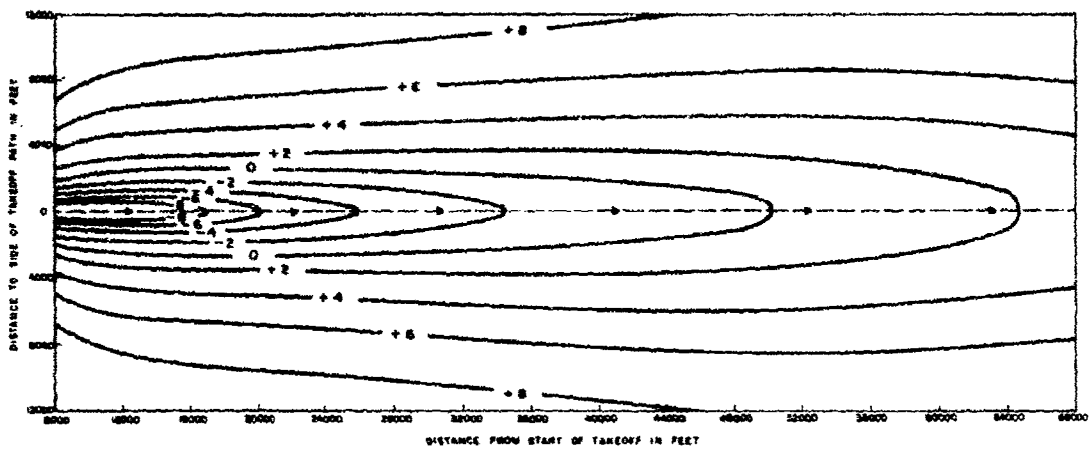
VI. EFFECTIVE PERCEIVED NOISE LEVEL CONTOURS

Perceived noise level contours are often used to depict the maximum levels expected at various ground positions near an aircraft flight path.6/ In a similar manner, contours of effective perceived noise levels may be developed. As shown previously in Figs. 8 and 10, a major effect of the time duration correction is to decrease the slope of the curve relating perceived noise level with distance between aircraft and ground positions. This results in an increase in the distance between contour intervals.

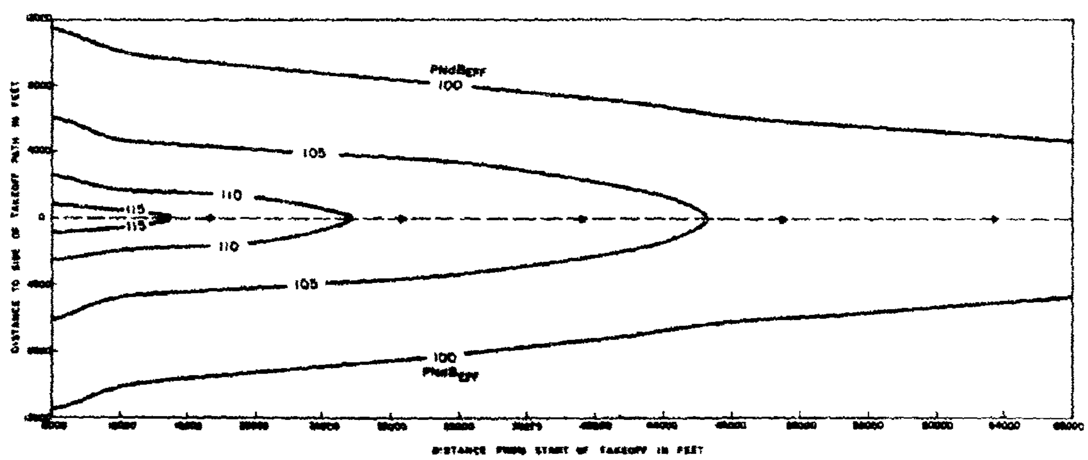
This situation is graphically illustrated in Fig. 12 where contours for the takeoff of a large turbojet transport aircraft are depicted. (These contours are based upon speed profile curve A and the altitude profile of Fig. 4.) The upper portion of the figure shows perceived noise level contours at 5-PNdB intervals for distances from 8000 to 68,000 ft from start of takeoff roll. The middle portion of Fig. 12 shows the time duration corrections in 2-PNdB intervals. The lower portion of Fig. 12 shows the resulting effective perceived noise level, reflecting the addition of the contours shown in the upper portions of the figure. Clearly evident is the increase in spacing between 5-PNdB intervals.



(A) PERCEIVED NOISE LEVEL CONTOURS



(B) TIME DURATION MODIFICATION $\left(15 \log_{10} \frac{\text{DURATION IN SEC.}}{\text{20 SEC.}}\right)$ CONTOURS



(C) EFFECTIVE (DURATION MODIFIED) PERCEIVED NOISE LEVEL CONTOURS

FIGURE 12. COMPARISON OF PERCEIVED NOISE LEVEL AND EFFECTIVE PERCEIVED NOISE LEVEL CONTOURS FOR TAKEOFF OF A LARGE TURBOJET TRANSPORT AIRCRAFT.

VII. CONCLUSIONS

This study has shown the following:

a) for a given type of aircraft flying at a constant power setting, the time duration of the noise signal received on ground may generally be represented by a near-linear function of the ratio of slant distance to speed.

b) for the typical ranges of airspeed encountered immediately after takeoff and during early phases of climb out, the time duration may be correlated with slant range with a typical spread in data of 2 to 3 PNdB for a particular aircraft.

c) interpretation of time duration in terms of effective PNdB produces a reduced slope of the curve relating PNdB with distance reflecting a lessening in the change of "noisiness" for a given slant distance range. This results in a marked lengthening of the interval between perceived-noise level contours.

REFERENCES

1. K. D. Kryter, "Scaling Human Reactions to the Sound from Aircraft", J. Acoust. Soc. Am., 31, 1415-1429 (1959).

2. K. D. Kryter, K. S. Pearsons, "Judgment Tests of the Sound from Piston, Turbojet and Turbofan Aircraft", Sound, 1, 24-31 (Mar.-Apr. 1962).

3. K. D. Kryter, K. S. Pearsons, "Some Effects of Spectral Content and Duration on Perceived Noise Level", J. Acoust. Soc. Am., 35, 866-883 (1963).

4. W. E. Clark, "An Approach to Analysis of Aircraft Noise Problems Using Computer-Aided Techniques", Part I of FAA SRDS Report No. RD-64-148 (Dec. 1964).

5. SAE ARP 866, "Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise", (1964).

6. Bolt Beranek and Newman Inc., Technical Report, "Land Use Planning Relating to Aircraft Noise", FAA (October 1964). Also published by Dept. of Defense as AFM 86-5, TM 5-365, NAVDOCKS P-98, "Land Use Planning with Respect to Aircraft Noise".

7. Boeing Airplane Co. Report T6-31113, "Model 727 Far Field Sound Characteristics During Ground Run-up, Takeoff and Landing", (1964).

8. Bolt Beranek and Newman Inc., "Studies of Noise Characteristics of the Boeing 707-120 Jet Airliner and of Large Conventional Propeller-Driven Airliners", (Oct. 1958).

FINAL REPORT

Contract No. FA-WA-4409

SRDS Report No. RD-65-130

Project 430-001-01R

PART VI

A STUDY OF AIRCRAFT FLYOVER NOISE VARIATIONS DUE TO CHANGES IN FLIGHT PATHS AND ATMOSPHERIC SOUND TRANSMISSION CHARACTERISTICS

December 1965

Prepared By

Dwight E. Bishop

Richard D. Horonjeff

BOLT BERANEK AND NEWMAN INC.
15808 Wyandotte Street
Van Nuys, California 91406

ABSTRACT

Variations in noise levels, observed at ground positions under and adjacent to aircraft flight paths, are examined by means of computer-simulated takeoffs of a large turbo-jet transport aircraft. Variations in noise levels arising from variations in flight track over ground and in altitude profiles and from changes in sound transmission characteristics of the atmosphere (due to temperature and humidity changes) are reviewed. From calculation of maximum flyover noise levels at 63 ground positions, charts are presented showing the range in noise levels produced by eight flight paths spaced about a mean takeoff flight path. Similarly, charts are presented showing ranges in noise levels resulting from four temperature-humidity combinations differing from the standard conditions of 59°F-70% relative humidity.

Flight path variations produce the maximum range in noise levels at ground positions near the mean flight path. Noise level variations due to air attenuation changes increase with distance between aircraft and ground positions. Noise levels, at temperature and humidity extremes are generally lower than those calculated for standard temperature and humidity conditions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

I. INTRODUCTION

This report examines, by means of computer-aided techniques, some of the variations in maximum noise levels observed on the ground during takeoffs of jet transport aircraft. Of the many factors contributing to observed variations in noise levels, variations arising from differences in flight paths and from changes in sound transmission characteristics of the atmosphere (due to temperature and humidity changes) are briefly reviewed.

In seeking to describe the very complicated noise environment existing in the vicinity of airports, most engineering descriptions consider noise in terms of aircraft noise characteristics and flight paths. Noise level estimates are often based on calculations using "typical" flight paths and standardized atmospheric conditions. This is a very useful approach since it permits defining a complicated physical environment in a meaningful, relatively clear manner which can lead to the understanding and solution of many aircraft noise problems. However, such simplifications in description can lead to difficulties when we seek to define boundaries for zones of expected community or individual behavior.

In practice, people in a community are exposed to a large number of flyovers with maximum noise levels at any given ground position varying over a considerable range. Thus, people are exposed to a distribution of noise levels rather than to a simply-defined single level of noise. This variability in flyover noise levels may limit the accuracy with which discrimination in subjective response can be reliably expected (or predicted from laboratory experiments) in real life aircraft noise environments.*

---

* This topic is discussed in more detail in Part I of this report.

For example, differences in subjective response, resulting from relatively small changes in the flyover noise levels, may be easily and consistently detectable in laboratory judgment tests. However, comparably small differences in the mean values of large samples of flyover noise signals, occurring over an extended time period, may not be noticeable. Thus some understanding of the variability in noise levels expected in real life aircraft noise environments is helpful in interpreting the results of noise judgment tests.

The sources of noise level variations observed in field measurements are many. Contributing factors are: differences in aircraft flight performance; differences in aircraft noise characteristics; differences in operational procedures and pilot techniques; differences in aircraft weights; and variations in weather conditions. Of these factors, this report considers only the variability which may arise due to variations in aircraft flight paths, and changes in atmospheric sound transmission characteristics arising from temperature and humidity changes. These are not necessarily the most significant variables; other sources of variability may, in many instances, be equally or more important. However, the two sources of variation discussed in this report lend themselves to analysis by computer-aided techniques. Thus, this study provides information which may be helpful in later exploration of other sources of noise level variations.

The following section reviews briefly the magnitude of noise level variations that have been observed by direct measurements at two major airports in this country. Section III then describes the computer analysis procedures employed, while the following sections of the report present results of the analysis and conclusions.

II. OBSERVED NOISE LEVEL VARIATIONS UNDER JET AIRCRAFT FLIGHT PATHS

Before discussing the variations arising from simulated aircraft flyovers, it is helpful to review the magnitude of variations found in field measurements. Figure 1 shows the distributions of noise levels observed in recent measurements at two locations at each of two major airports. Shown are distributions measured at three positions under takeoff paths, and at one position under a landing path. Locations for the various measurements are given in the accompanying Table I.

Figure 1 shows the standard deviation and the 25th, 50th, and 75th percentile of the distributions observed at each position. The standard deviation values range from 5.2 to 8.8 PNdB; the range for 50% of the measurements (semi-quartile range) vary from 7 to almost 10 PNdB. The measurements reported in Fig. 1 are for positions near well-defined landing or takeoff paths. One would expect to find even greater variations near airports where flight paths are more divergent.

The distributions shown in the figure result, of course, from noise produced by a variety of types of turbojet and turbofan aircraft. The distributions would be broadened if noise from propeller transport aircraft had been included. On the other hand, one would expect that if measurements were confined to a single type of aircraft, the distributions would be somewhat less.

The data shown in Fig. 1 were obtained from measurements at several intervals within several week time periods. Measurements at intervals over an extended time period might well show even greater variability as a result of aircraft operations over a wider range of weather conditions.

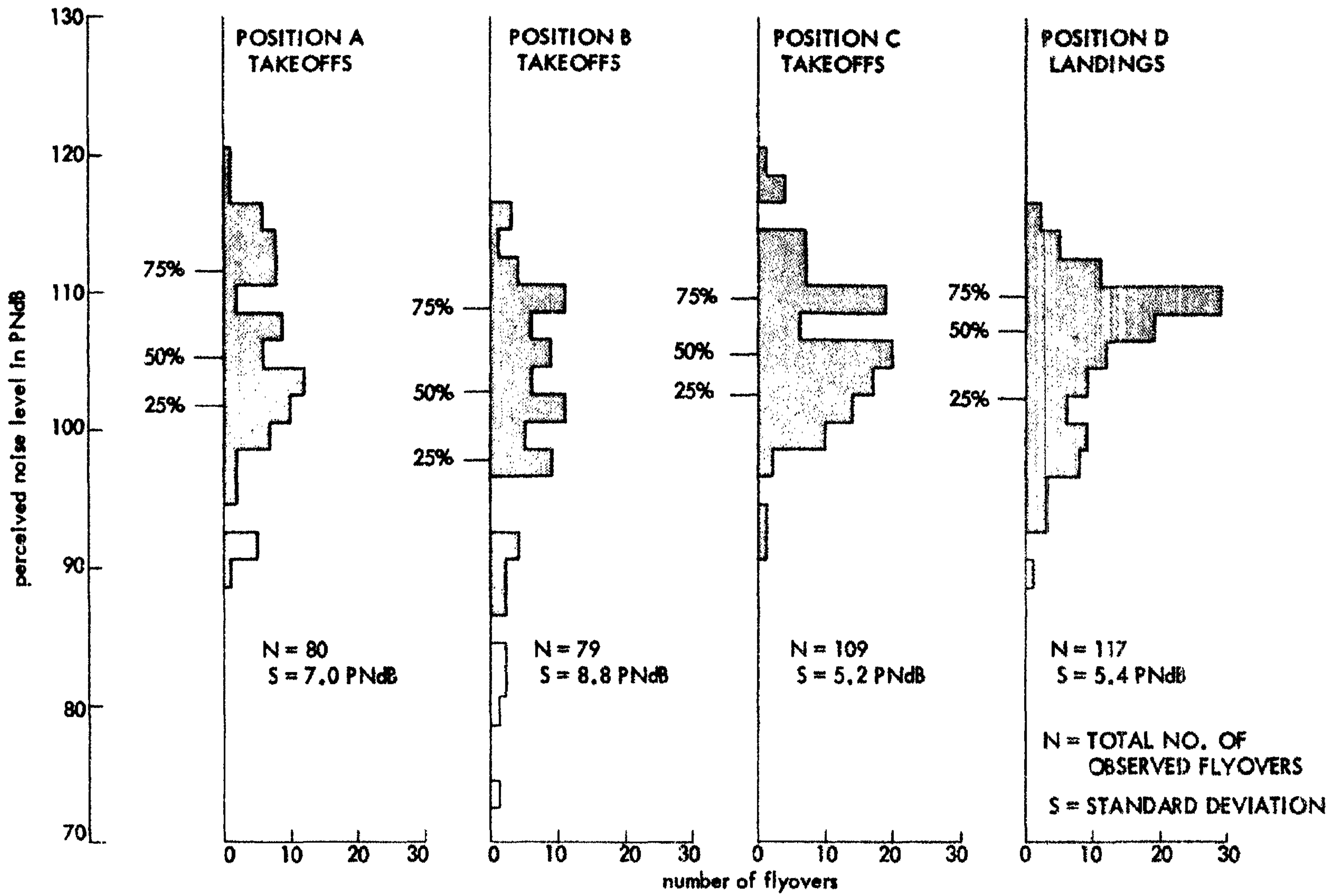


FIGURE 1. TYPICAL DISTRIBUTIONS OF JET FLYOVER NOISE LEVELS OBSERVED NEAR MAJOR TAKEOFF OR DEPARTURE PATHS

TABLE I

LOCATION OF AIRCRAFT NOISE
MEASUREMENT POSITIONS

(See Figure 1)

Position	Airport	Location
A	John F. Kennedy International Airport, New York	19,400 ft from start of Runway 13R, 900 ft to side of projected runway centerline
B	John F. Kennedy International Airport, New York	24,000 ft from start of Runway 13R, directly beneath flight path
C	Los Angeles International Airport	14,000 ft from start of Runway 25L, 800 ft to side of projected runway centerline
D	Los Angeles International Airport	8100 ft from landing threshhold of Runway 25L, directly beneath flight path

III. ANALYSIS PROCEDURE

Computer techniques were used to simulate the takeoffs of a large turbojet transport. In this simulation, the maximum noise levels occurring for different aircraft flights were collected at a grid of ground positions located under and to one side of the aircraft takeoff path. Input information consisted of: aircraft flight track over the ground; altitude profile along the flight track; air attenuation values; and noise spectra for the aircraft specified in octave frequency bands at 10° intervals about the aircraft.

The computer studies were made on a Digital Equipment Corporation computer, Model PDP-1. Information input to the computer was by means of typewriter or by transcribing graphical information using a special graphical input device. Graphical output was obtained from a paper-ink plotter.

For each simulated aircraft flight, the computer calculated and collected the maximum perceived noise level (to the nearest whole PNdB) for each grid point. Output of the program consisted of sets of perceived noise levels, one for each flyover, at each of the grid points. The computer also tabulated the maximum and minimum noise level observed for the set of flyovers at each grid point. The reference noise spectrum for the simulated aircraft, described in terms of the maximum octave band noise levels observed at a distance of 1000 ft from the aircraft during a flyover, is shown in Fig. 2.

A straight flight track over the ground and an altitude profile, defined as the geometric mean of the "long range" and "short range" profiles given in Reference 1, was chosen to define the mean flight path for the simulated takeoffs. This mean path is sketched in Fig. 3. Eight additional paths, also shown in Fig. 3, were chosen to explore flight track and altitude profile variations. These eight paths were spaced about the mean path to approximate the boundaries of an ellipse as indicated in Section A-A in the figure. The standard air attenuation

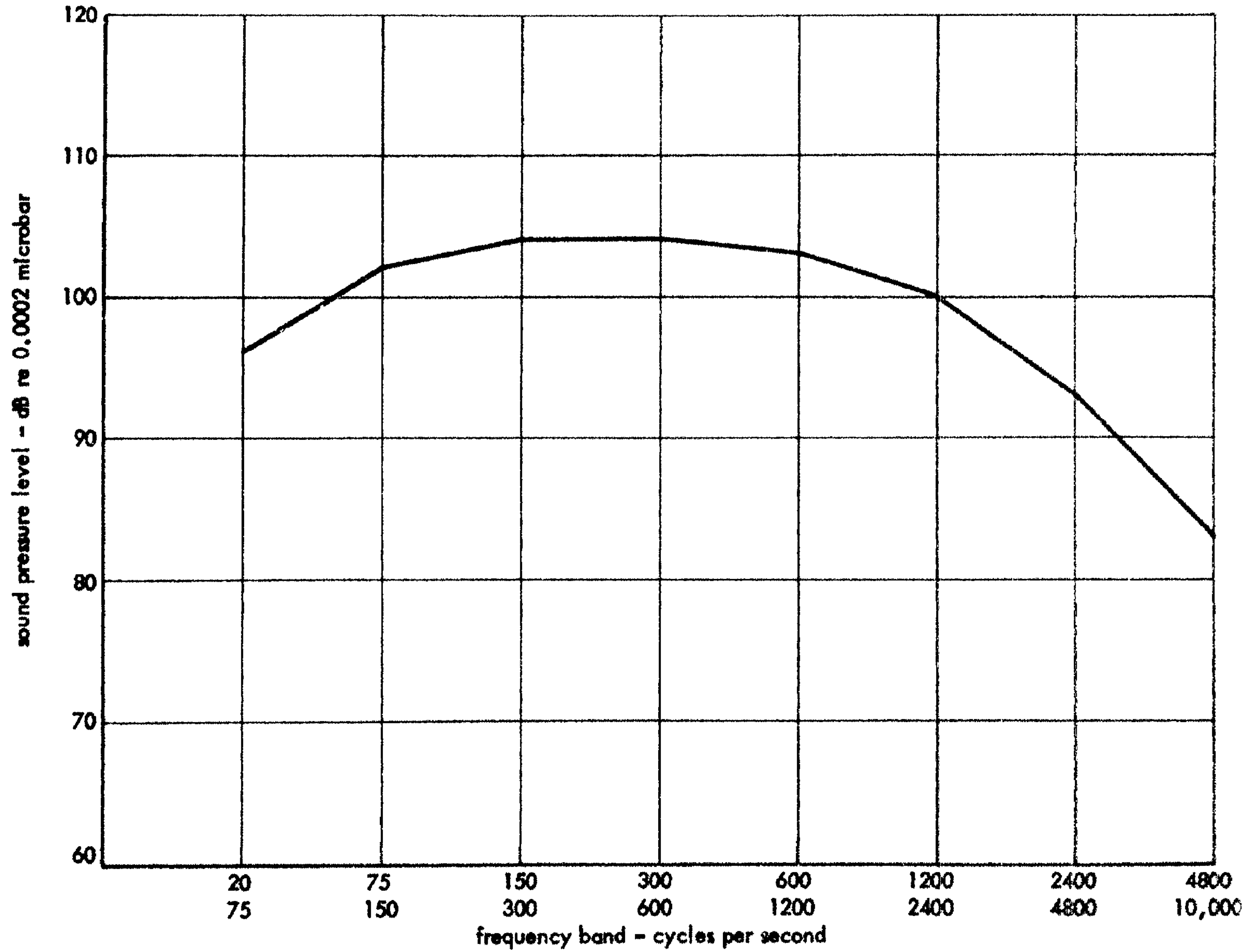
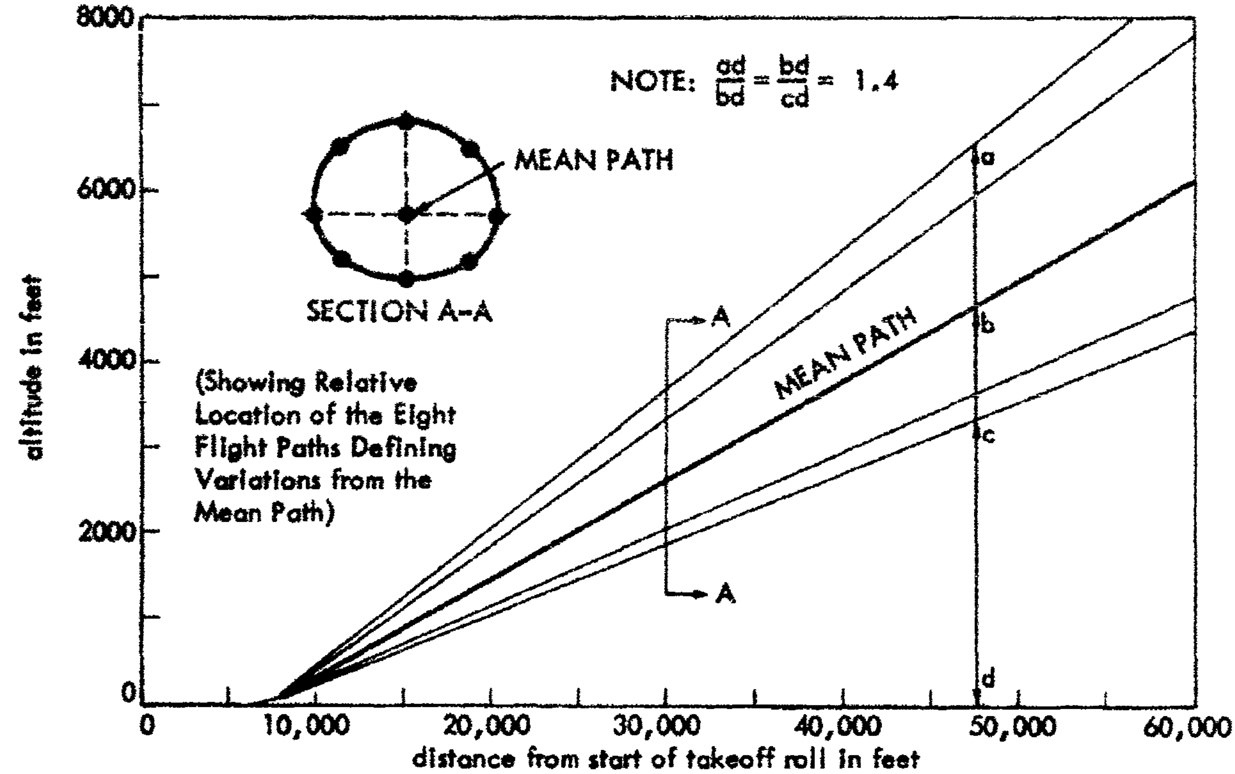


FIGURE 2. NOISE SPECTRUM FOR SIMULATED TAKEOFFS OF A LARGE TURBOJET TRANSPORT AIRCRAFT (MAXIMUM LEVELS AT A POINT 1000 FT. FROM FLIGHT TRACK)



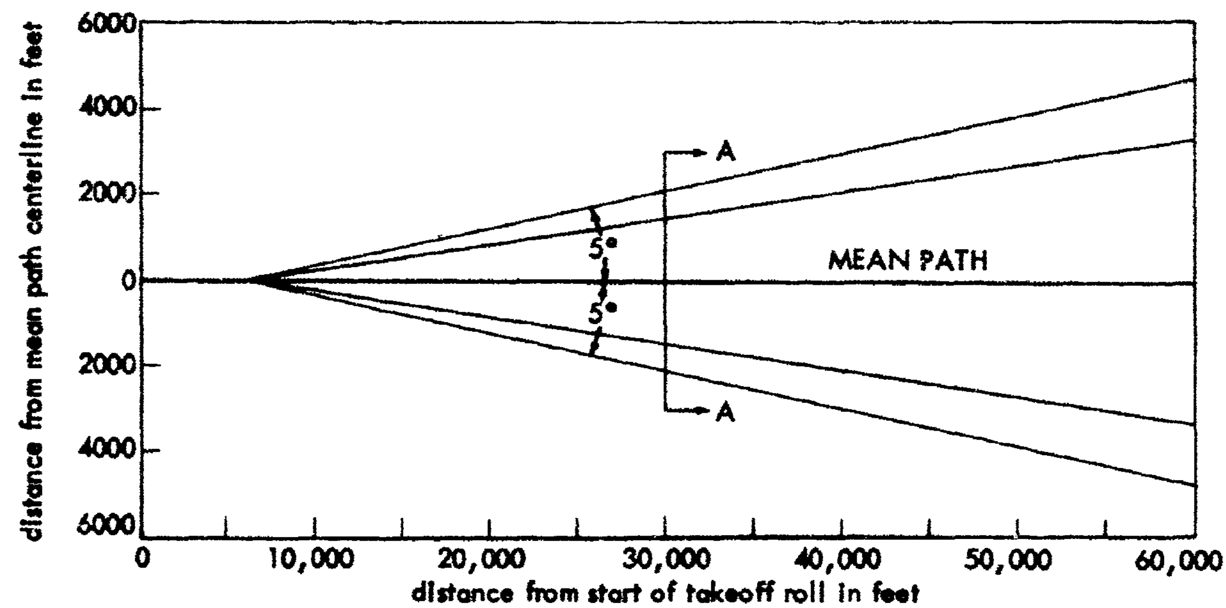


FIGURE 3. FLIGHT TRACK AND ALTITUDE PROFILES FOR SIMULATED TURBOJET TRANSPORT AIRCRAFT TAKEOFFS

values recommended in Ref. 3 (and tabulated in Table II) for 59°F temperature and 70% relative humidity were employed in the computer calculations.

In attempting to select realistic values for the magnitude of deviations about the mean altitude profile, we reviewed the altitude variations observed at four positions near the takeoff path from Runway 13R at the John F. Kennedy Airport in New York.2/ Since the aircraft noise levels expressed in decibels tend to vary linearly with the logarithm of the altitudes, the observed altitudes were plotted on a logarithmic scale. At each position, we found that the standard deviation for the observed altitudes, expressed as a logarithm, approximated 0.15, equivalent to an altitude ratio of 1.4. Therefore, in selecting the extent of deviations from the mean altitude profile, we chose a value of 1.4 for the ratio of maximum to mean altitude and for the ratio of mean to minimum altitude (i.e., for a mean altitude of 1000 ft, maximum and minimum altitudes were 1400 ft [1400/1000 = 1.4] and 714 ft [1000/714 = 1.4]).

In considering deviations of the flight track, similar detailed experimental information was not available. Therefore, a maximum deviation from a straight flight path of ±5°, beginning at 6000 ft from start of takeoff roll, was assumed. This assumption may be somewhat unrealistic in that it is likely that the angular deviations from a straight-out flight path would increase with distance from takeoff, and would not remain constant, as assumed in this study.

Noise levels were computed at 63 ground positions. These positions were located at intervals of 5000 ft over the range from 10,000 ft to 50,000 ft from start of takeoff roll, and at intervals of 2000 ft from the mean path centerline to a distance of 12,000 ft to one side of the mean track.

To obtain an indication of the variation in noise levels resulting from changes in air attenuation due to changes in temperature and relative humidity, we simulated the (single) mean flight track and altitude profile of Fig. 3 and introduced air attenuation values for four additional temperature-humidity combinations of 90°F-10%, 90°F-90%, 30°F-10%, and 30°F-90%. These air attenuation values, computed from Ref. 3, are tabulated in Table II. These temperature limits do not necessarily coincide with limits at any particular airport, but rather represent deviations from standard values that were felt not to be unusual.

TABLE II

AIR ATTENUATION VALUES
USED IN SIMULATED AIRCRAFT TAKEOFF

Octave Frequency Band, cps	AIR ATTENUATION IN dB PER 1000 FT				
	59%	90°F		30°F	
	70% R.H.	10% R.H.	90% R.H.	10% R.H.	90% R.H.
37-75	--	--	--	--	--
75-150	--	0.21	0.21	0.4	0.01
150-300	--	0.42	0.42	1.1	0.22
300-600	0.6	0.9	0.9	2.0	0.5
600-1200	1.1	2.5	1.6	3.3	1.1
1200-2400	2.5	7.5	3.6	4.0	3.5
2400-4800	6.2	20.7	7.5	5.6	9.8
4800-9600	11.3	39.0	11.2	7.0	15.0

The resulting noise levels at the 63 ground positions were then computed for these temperature-humidity combinations based on the turbojet noise spectrum of Fig. 2* and the (single) mean flight track and altitude profile of Fig. 3.

* Actually, noise levels for the different temperature-humidity calculations were calculated from a reference spectrum defined at a radius of 200 ft from the aircraft.

IV. ANALYSIS OF FLIGHT PATH AND TEMPERATURE-HUMIDITY CHANGES

Figure 4 shows the range of perceived noise levels at ground positions directly underneath the mean path, and at ground positions displaced 8000 ft to one side of the mean path resulting from the nine simulated flight paths of Fig. 3. Also shown are heavy lines representing the values observed for simulated flight along the mean path. Figure 5 shows, in a similar manner, the range in levels observed at ground positions perpendicular to the mean flight track along lines 10,000 ft and 40,000 ft from the start of the takeoff roll.

We note from Fig. 4 that the range in noise levels directly under the mean flight path is relatively constant, varying from 7 to 10 PNdB. For positions displaced 8000 ft from the mean flight path, we note that the range tends to increase with distance from takeoff roll, increasing from 1 PNdB at 10,000 ft from start of takeoff roll to a maximum of 7 PNdB at 50,000 ft from start of takeoff roll.

From Fig. 5 we note that the range in noise levels is less for positions displaced well to one side of the flight path. For instance, along the line 10,000 ft from start of takeoff roll, the range decreases from 7 PNdB directly under the flight path to 1 PNdB for positions 8000 ft or more from the main flight path. Variation is less pronounced at a distance of 40,000 ft; in this case, the maximum range of 10 PNdB is observed not directly under the mean flight path, but at 4000 ft from the mean flight path. At greater distances to the side of the flight path the range in values is less.

This decrease in noise level range at large distances to one side of the flight path is, of course, expected. At relatively large distances from the flight path sizeable variations in flight path altitude or ground track result in relatively small changes in the actual distance between the aircraft and ground positions. However, the maximum variation may not necessarily occur directly under the flight path, but at some intermediate distance.

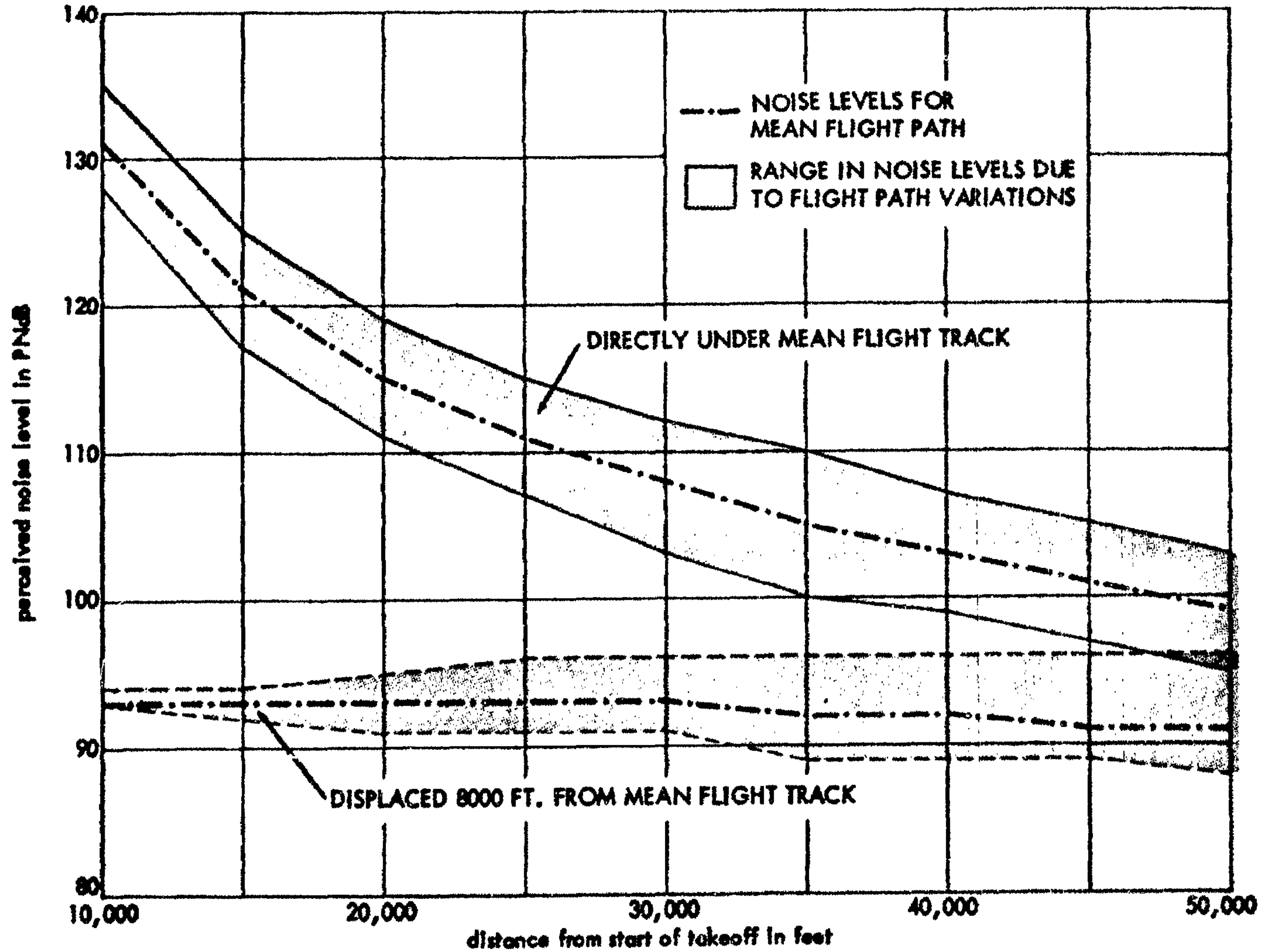


FIGURE 4. PERCEIVED NOISE LEVELS RESULTING FROM TURBOJET TAKEOFF PATH VARIATIONS (AT GROUND POSITIONS PARALLEL TO MEAN FLIGHT PATH) 59°F., 70% RELATIVE HUMIDITY

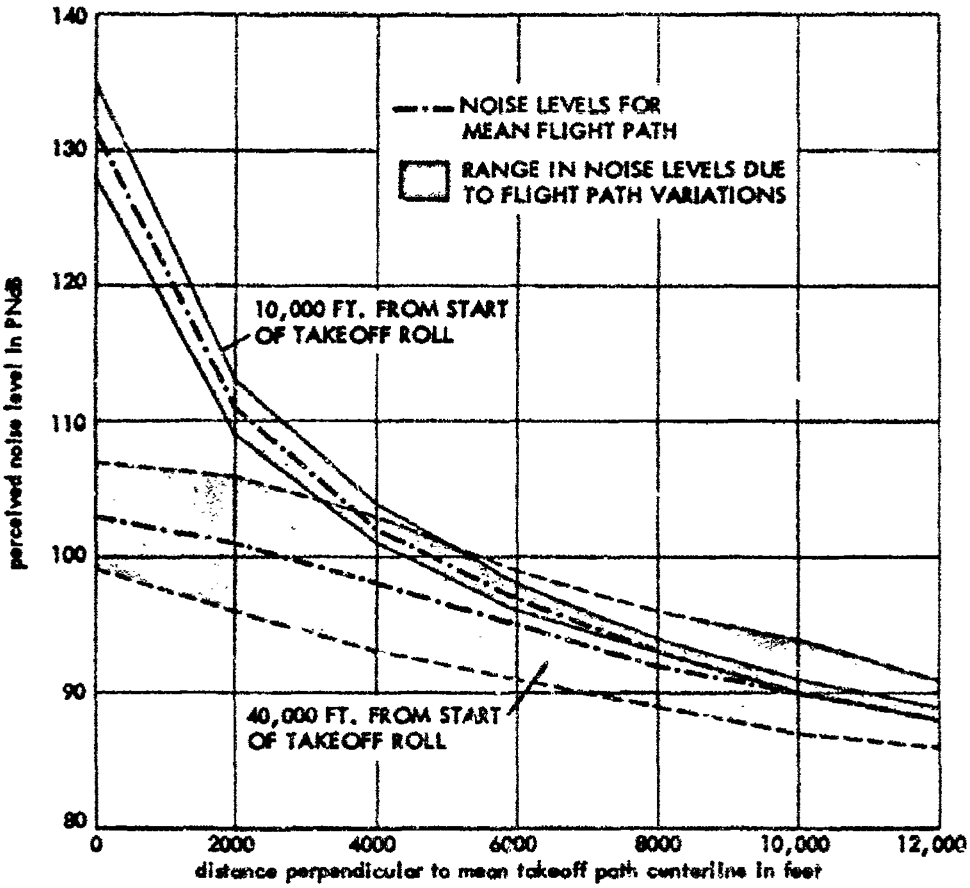


FIGURE 5. PERCEIVED NOISE LEVELS RESULTING FROM TURBOJET TAKEOFF PATH VARIATIONS (AT GROUND POSITIONS PERPENDICULAR TO MEAN FLIGHT PATH) 59°F., 70% RELATIVE HUMIDITY

The relative size of noise level variations may be visualized by display in terms of contours. Figure 6 shows contours of the range in noise levels drawn at 2-PNdB intervals, based on the variations observed at the 63 ground positions. These contours clearly show that the maximum variations tend to occur near the extreme flight track deviations, not directly under the mean track.

As might be expected, we may also note from Figs. 4 and 5 that noise levels for flyovers following the mean path fall near the middle of the noise level range. Hence path variations produce noise levels ranging well above and below those calculated for the mean path.

We can now examine in a similar manner the variation in takeoff noise levels due to temperature and humidity changes. Figure 7 shows shaded bands, depicting the range of noise levels, measured at ground positions parallel to the mean flight track for the five temperature-humidity combinations of 59°F-70%, 90°F-10%, 90°F-90%, 30°F-10% and 30°F-90%. The upper shaded band depicts noise levels for positions directly below the mean flight path, the lower shaded band for positions displaced 8000 ft to one side. Figure 8 shows shaded bands for noise level ranges observed at positions perpendicular to the mean flight path at 10,000 ft and 50,000 ft from the start of takeoff roll. (These figures may be compared with corresponding Figs. 4 and 5 for path variations.)

We would expect the variation in noise levels due to changes in atmospheric attenuation to increase with distance between the aircraft and a ground position, since the excess attenuation is a linear function of distance.

This expectation is confirmed in the figures. For example, in Fig. 7, the spread in noise levels observed 8000 ft from the mean path is greater than that observed directly under the flight path. This variation is also clearly evidenced in Fig. 8, where the variation increases from 1 PNdB to 13 PNdB for distances perpendicular to the flight track

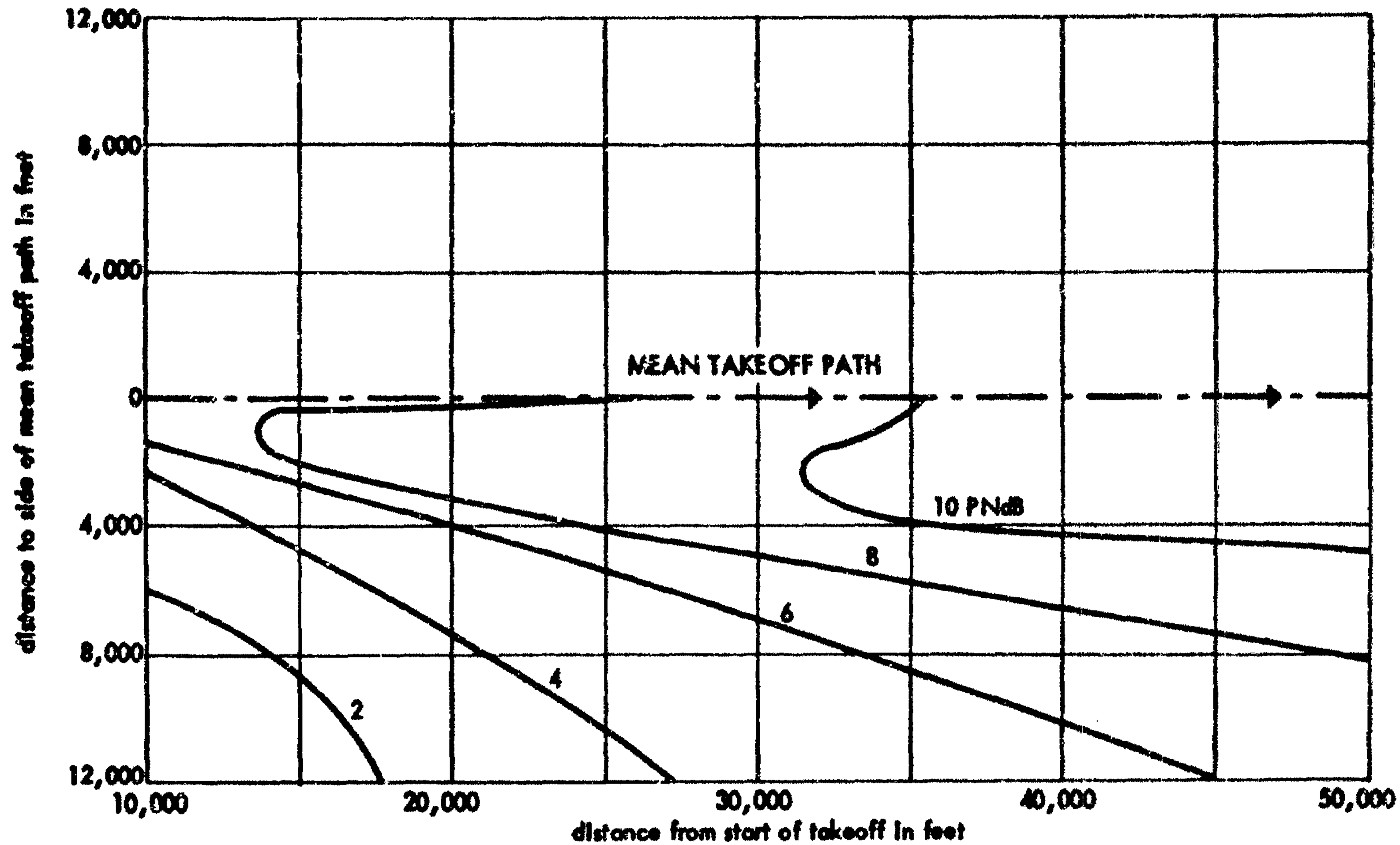


FIGURE 6. CONTOURS OF THE RANGE IN PERCEIVED NOISE LEVELS RESULTING FROM THE FLIGHT PATH VARIATIONS OF FIGURE 3. (SIMULATED TURBOJET TRANSPORT AIRCRAFT TAKEOFFS)

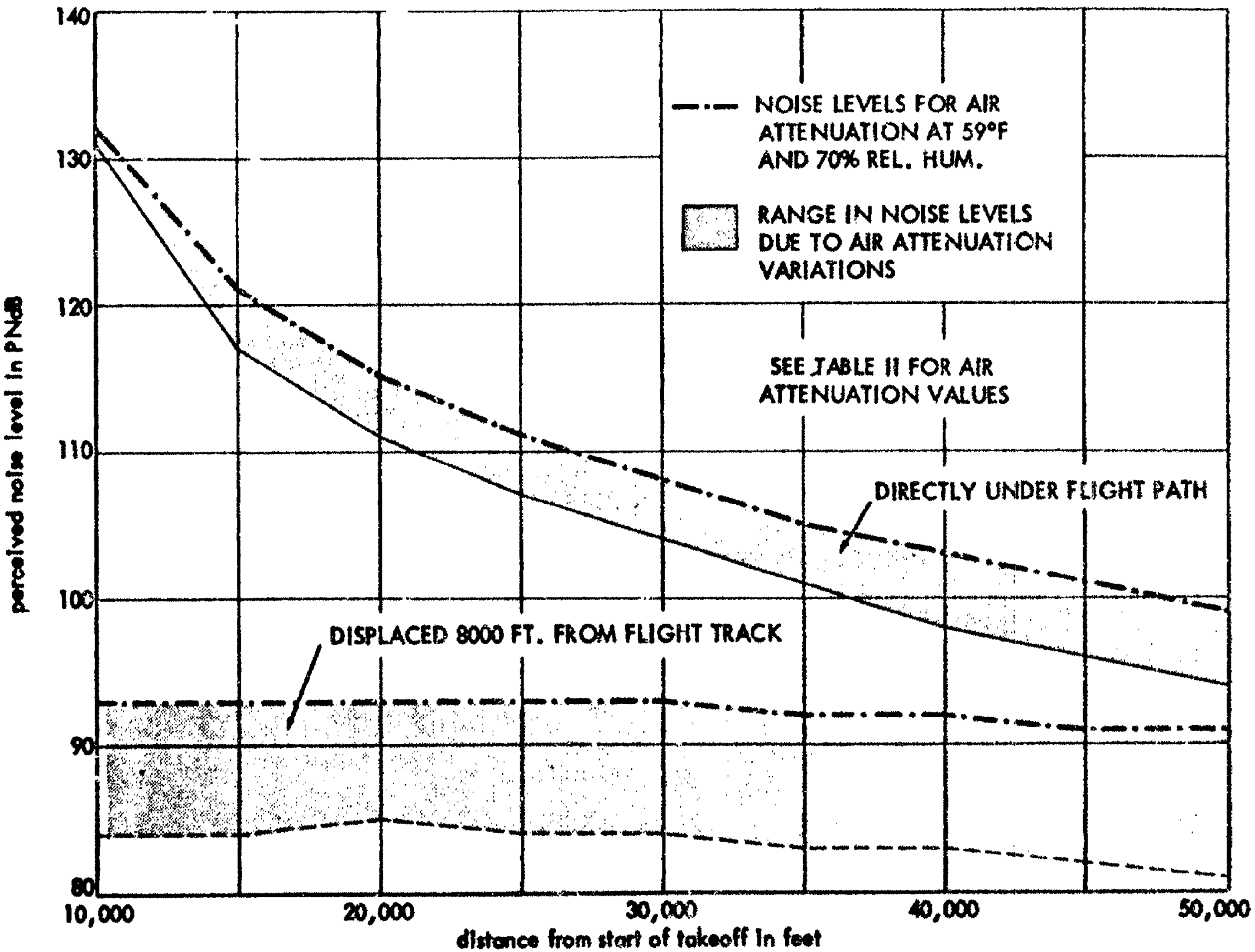


FIGURE 7. PERCEIVED NOISE LEVELS RESULTING FROM AIR ATTENUATION VARIATIONS (AT GROUND POSITIONS PARALLEL TO TURBOJET TAKEOFF FLIGHT PATH)

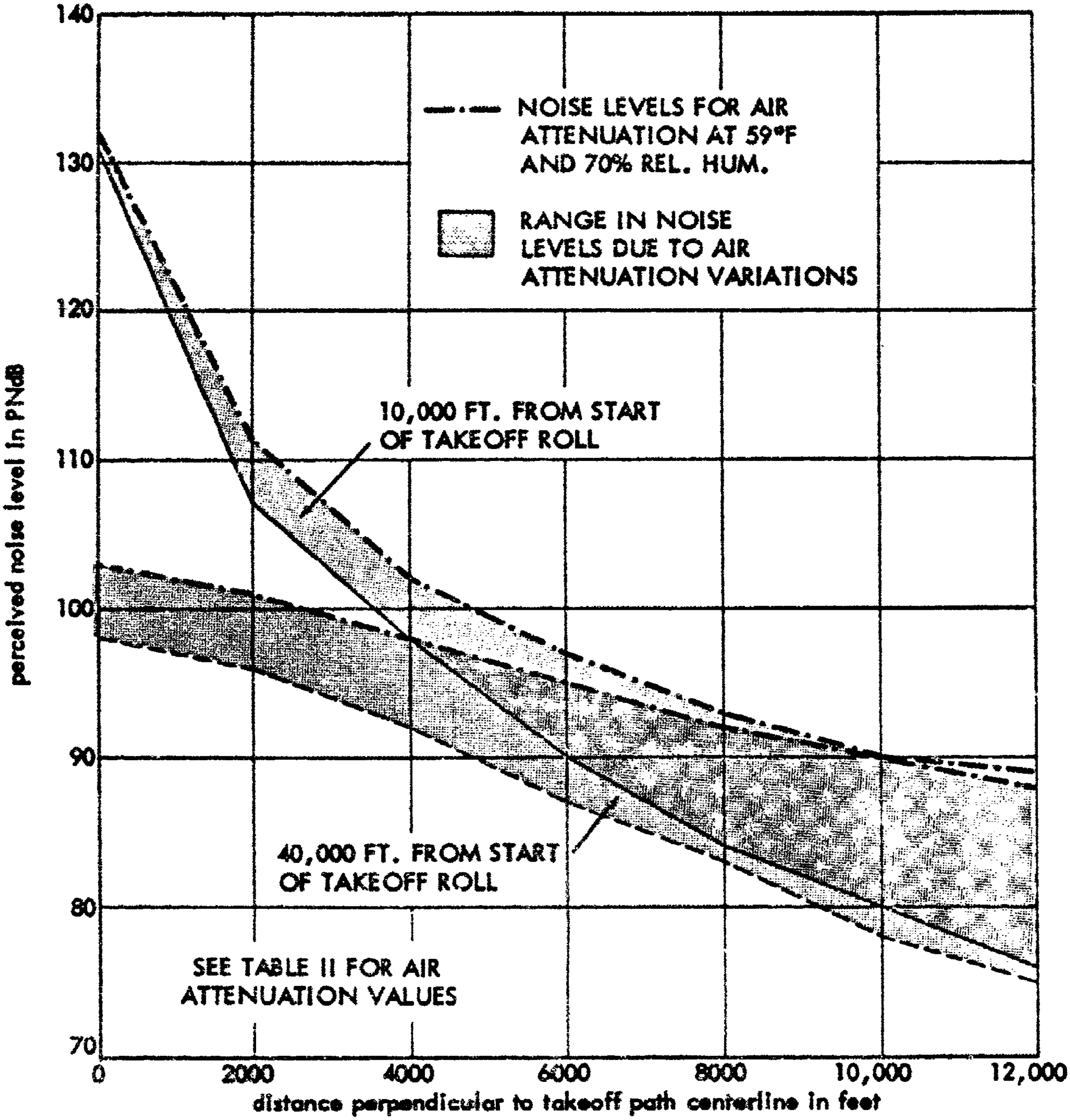


FIGURE 8. PERCEIVED NOISE LEVELS RESULTING FROM AIR ATTENUATION VARIATIONS (AT GROUND POSITIONS PERPENDICULAR TO TURBOJET TAKEOFF FLIGHT PATH)

at 10,000 ft from the start of takeoff roll. At 40,000 ft from start of takeoff roll, where the aircraft has attained a considerably higher altitude, the variation increases from 5 PNdB directly under the flight path to 13 PNdB at a distance 10,000 ft from the flight path.

In Figs. 7 and 8 we have also shown the noise levels observed for the standard conditions of 59°F and 70% relative humidity by heavy dashed lines. The noise levels for these "standard" temperature and humidity conditions form the upper boundaries of the variations. Thus, the standard-day conditions seem quite conservative, in that they lead to higher estimates of noise levels than will often be encountered in many field situations.

It should be emphasized that the above simulations do not include the effects of temperature and humidity changes on engine thrust or engine noise generation. For example, under "hot-day" conditions, the engine would produce less thrust. Thus, climb gradients would be less, resulting in lower altitudes (and higher noise levels) at a given position from start of the takeoff. Tending to offset this condition is the reduced noise output from jet engines at the higher temperature. The relative amounts of noise reduction and altitude profile differences will depend on details of specific types of aircraft and engines.

In manner similar to that used in Fig. 6, the variation in noise levels due to atmospheric changes may be displayed by means of contours. Figure 9 shows contours of equal-PNdB variations, due to variability of air attenuation. Note here that the contours resemble the contours showing maximum noise levels, (i.e., the maximum variation tends to increase with distance from aircraft to ground positions).

Another way of displaying the extent of variations due to flight path and atmospheric attenuation variability is to display the maximum and minimum noise levels in the form of noise contours. Figures 10 and 11 show 110-, 100- and 90-PNdB noise contours for maximum and

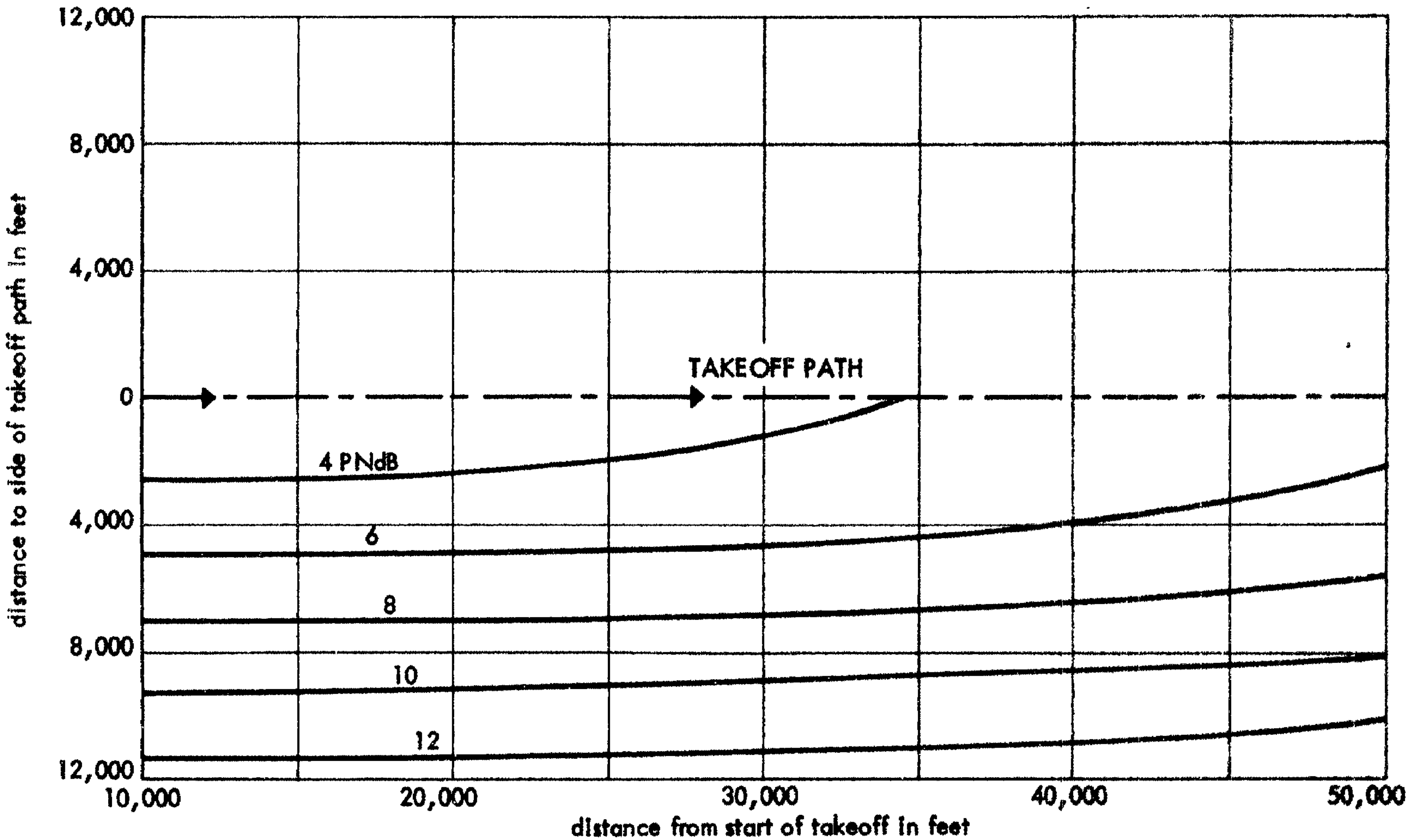


FIGURE 9. CONTOURS OF THE RANGE IN PERCEIVED NOISE LEVELS RESULTING FROM AIR ATTENUATION VARIATIONS (SIMULATED TURBOJET TRANSPORT AIRCRAFT TAKEOFFS)

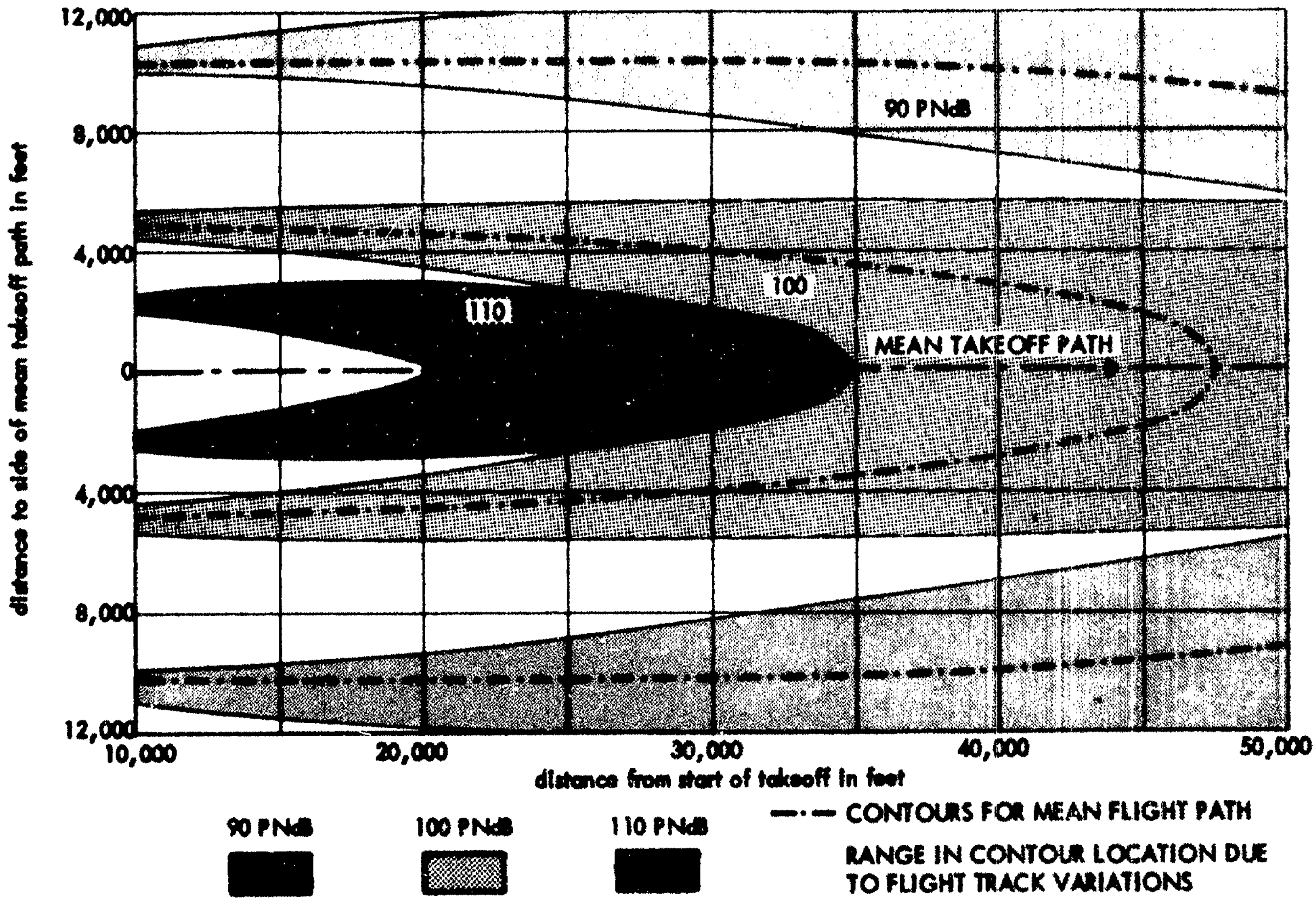


FIGURE 10. PERCEIVED NOISE LEVEL CONTOUR CHANGES RESULTING FROM THE NINE FLIGHT PATH VARIATIONS OF FIGURE 3. (SIMULATED TURBOJET TRANSPORT AIRCRAFT TAKEOFFS)

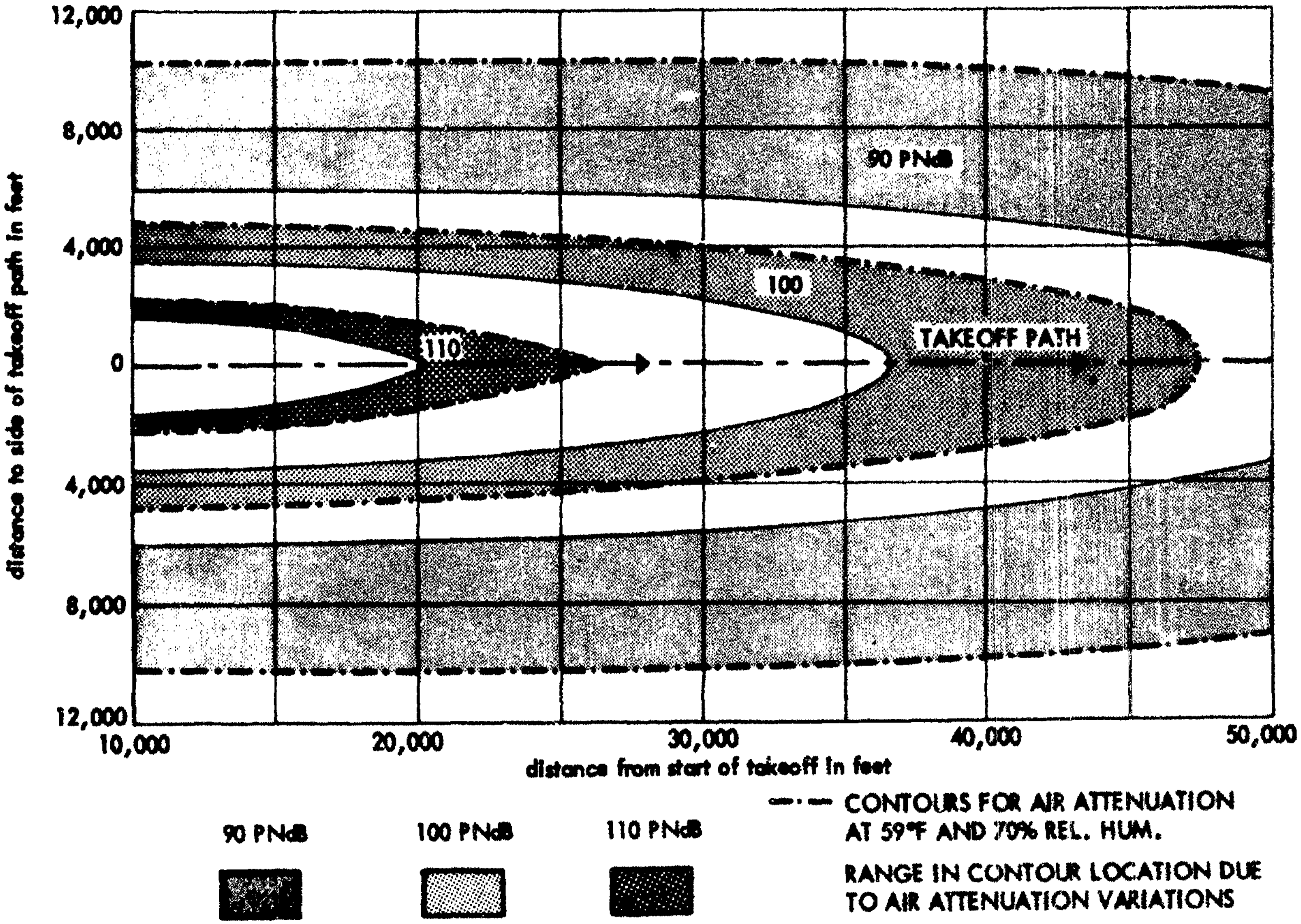


FIGURE 11. PERCEIVED NOISE LEVEL CONTOUR CHANGES RESULTING FROM THE FIVE AIR ATTENUATION VARIATIONS OF TABLE II. (SIMULATED TURBOJET TRANSPORT AIRCRAFT TAKEOFFS)

minimum values of the computed noise levels. Figure 10 shows the contours for flight path variations. Figure 11 shows the contours for the air attenuation variations. Also shown are the heavy dashed lines representing noise contours for the mean flight path and standard-day attenuation values. The shaded areas in both figures show the range in area corresponding to changes in the noise contours for the variations studied.

Clearly evident here are the trends in variations previously discussed. For example, in Fig. 10 we see that the variations tend to be as great under the flight path as for distances well off to either side. However, in Fig. 11, we see that the contour variations tend to increase as distances between aircraft and ground positions increase.

V. SUMMARY AND CONCLUSIONS

In this report we have demonstrated, by means of a number of computer-simulated flyovers of turbojet transport aircraft, typical variations in noise levels produced by variability in flight paths and in atmospheric attenuation of noise signals. The demonstration shows that:

a) path variations produce the maximum range in noise levels at ground positions near the mean flight track; this range in noise levels decreases with increasing distance between the aircraft and ground positions

b) noise level variations due to air attenuation variations (temperature and relative humidity changes) increase with distance between aircraft and ground positions. Comparison of noise levels at temperature and humidity extremes, with those computed for standard temperature and humidity conditions, indicates that the standard air attenuation values result in conservative (i.e., high) values of noise levels.

REFERENCES

1. Bolt Beranek and Newman Inc. Technical Report, "Land Use Planning Relating to Aircraft Noise", FAA (Oct. 1964). Also published by the Dept. of Defense as AFM 86-5, TM 5-365, NAVDOCKS P-98, "Land Use Planning With Respect to Aircraft Noise".

2. FAA Technical Report ADS-41, "Study of the Effect of Departure Procedures on the Noise Produced by Jet Transport Aircraft", (1965).

3. SAE ARP 866, "Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise", (1964).

FINAL REPORT

Contract No. FA-WA-4409

SRDS Report No. RD-65-130

Project 430-001-01R

PART VII

APPLICATIONS OF METHODS FOR RATING LAND USE COMPATIBILITY WITH AIRCRAFT NOISE

December 1965

Prepared By

Dwight E. Bishop

"This report has been prepared by Bolt Bernaek d Newman Inc. for the Systems Research and Development Service, Federal Aviation Agency, under Contract No. FA-WA-4409. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA. This report does not constitute a standard, specification or regulation."

BOLT BERANEK AND NEWMAN INC.
15808 Wyandotte Street
Van Nuys, California 91406

ABSTRACT

Technical approaches in applying the methods for rating land use compatibility, given in Part II of FAA Report No. RD-64-148, are demonstrated. Actual generalized land use information for the vicinity of four airports has been utilized to determine the approximate extent of land uses, under and adjacent to various takeoff and landing paths which may be judged "marginal" or "unsatisfactory", with respect to compatibility with aircraft noise.

TABLE OF CONTENTS

I. INTRODUCTION

This report summarizes results of some applications of the method for rating land use compatibility with aircraft noise, developed in Part II of FAA Report No. RD-64-148.[1] The applications involve actual land use and flight information at four airports. However, since the purpose of the study was to demonstrate methods and illustrate technical approaches, the analysis has been purposely limited in detail and scope.

Nine sets of takeoff or landing operations at four airports were considered in this study. The procedure followed in the study consisted of four major steps:

a) from information concerning aircraft flight paths and type of aircraft, noise contours were constructed for land areas under and adjacent to the flight path. The noise contours were developed either by hand calculation procedures, using the generalized aircraft noise characteristics given in Reference 2, or by computer techniques.

b) from estimates of the number of aircraft operations, and runway utilization, Composite Noise Rating (CNR) contours were established from the perceived noise level contours.*

c) Noise Sensitivity Zones were defined by means of the appropriate CNR contours, in accordance with Table I (reprinted from Reference 1).

---

* Correction factors, dependent upon number of operations and runway utilization, are applied to the perceived noise levels to obtain the Composite Noise Ratings.

TABLE I

LAND USE COMPATIBILITY CHART FOR AIRCRAFT NOISE

Noise Sensitivity Zone	Composite Noise Rating (CNR)		LAND USE COMPATIBILITY								
	Takeoffs and Landings	Ground Runups	Residential	Commercial	Hotel, Motel	Offices, Public Buildings	Schools, Hospitals Churches	Theaters, Auditoriums	Outdoor Amphi-Theaters, Theaters	Outdoor Recreational (Non-spectator)	Industrial
I	Less Than 90	Less Than 70	yes	yes	yes	yes	yes	Note (A)	Note (A)	yes	yes
II	90-100	70-80	yes	yes	yes	yes	Note (C)	Note (C)	no	yes	yes
III	100-115	80-95	Note (B)	yes	Note (C)	Note (C)	no	no	no	yes	yes
IV	Greater Than 115	Greater Than 95	no	Note (C)	no	no	no	no	no	yes	Note (C)

NOTE (A) - A detailed noise analysis by qualified personnel should be undertaken for all indoor or outdoor music auditoriums and all outdoor theaters.

(B) - Case history experience indicates that individuals in private residences may complain, perhaps vigorously. Concerted group action is possible. New single dwelling construction should generally be avoided. For high density dwellings (apartments) construction, Note (C) will apply.

(C) - Avoid construction unless a detailed analysis of noise reduction requirements is made and needed noise control features are included in building design.

d) Noise Sensitivity Zone charts were overlayed on land use maps. The areas of principal land uses lying in the Noise Sensitivity Zones II, III and IV were then determined.

In addition to the above, in several instances the population lying within the Noise Sensitivity Zones was determined from available census information.

Section II of this report summarizes the analysis procedures; Section III discusses the interpretation procedures followed in this study. The following section summarizes the results of the specific airport and runway situations.

II. ANALYSIS PROCEDURES

As mentioned previously the noise contours were developed either by hand calculation procedures2/ or by computer.3/ After overlay of the contours upon the land-use maps, the problem arose of determining the areas of different land-use categories falling within the different noise contour boundaries. For this study, the areas were determined by tracing over the boundaries of the land areas and noise contours with a planimeter.

Originally, we had planned to use a computer to calculate land areas using a graphical input device3/ to trace the land areas and noise contour boundaries. The computer approach has the advantage that once the land-use information is stored in the computer, it can be quickly recalled for subsequent manipulations. However, the time required for initial input of this information into the computer was found to be approximately equal to the time required to obtain the land areas by using a planimeter, since both methods depend upon manual tracing of the land boundaries. Since we did not need to recall the land-use information for subsequent manipulations, there was no advantage in our using the computer, hence the areas were determined with a planimeter.

III. LAND USE INTERPRETATIONS

Table I shows the four Noise Sensitivity Zones, together with an interpretation of the sensitivity in terms of major categories of land use. For most of the land use categories, the compatibility rating for Noise Sensitivity Zone I is rated as "yes", indicating that there should be no adverse effects from the aircraft noise. As noise exposure is increased, denoted by an increasing CNR rating, some of the land use columns have the word "no" printed. "No" indicates that unless extensive (and often expensive) construction precautions are taken, noise will constitute a severe interference to land use. Between the "yes" and "no" rating, there is usually a range of CNR values where noise may introduce noticeable interference of varying degrees of importance. Depending on particular circumstances, such interference may give rise to moderate or even severe objections to the aircraft noise.

One major limitation of our study should be mentioned. The generalized land use maps available to us categorized land use only in such broad categories as: residential, commercial, industrial, and (depending upon the particular map) such other categories as undeveloped, agricultural, recreational, etc. The land use maps did not usually denote the location of schools, hospitals, libraries, churches, auditoriums or other buildings where work activities may be particularly sensitive to aircraft noise. Nor did the broad classification of "commercial" allow us to identify hotels, motels and theaters which may have much greater sensitivity to noise than supermarkets, garages or various other commercial establishments.

More detailed land use maps are often available (or can be compiled) for many communities. Such detailed land use information should, of course, be utilized in intensive studies of land use compatibility at individual airports and communities.

Use of generalized land use information, with consequent reduction in detail as mentioned above, permitted us to

simplify the interpretation of Table I as follows:

a) in the Noise Sensitivity Zones I and II, no land use need be termed "unsatisfactory" with respect to aircraft noise

b) in Noise Sensitivity Zone III, residential land use may be termed "marginal"

c) in Noise Sensitivity Zone IV, residential land use may be termed "unsatisfactory", and both industrial and commercial land use are judged "marginal".

Figure 1 illustrates the methods of obtaining the land use data listed in the table. This figure shows CNR contours for a takeoff path from Runway 5 at the Municipal Airport in Birmingham, Alabama. These contours (generated by computer, in this instance) are displayed on a generalized land use map.4/ From the land use map with superimposed contours, areas of various land uses falling within the different Noise Sensitivity Zones were determined by planimeter.

For the Birmingham, Alabama area, population information was available in the form of a map with dots distributed over the map, with each dot representing a given unit of population. For other localities, population estimates were obtained by first determining the average density of population per unit area in various census tracts.* Then, the area of each census tract lying within the various Noise Sensitivity Zones was determined. The product of the land area and average density yielded estimates of the population for each census tract lying within the given Noise Sensitivity Zone.

---

* "U. S. Censuses of Population and Housing: 1960" reports were used as sources for this information.

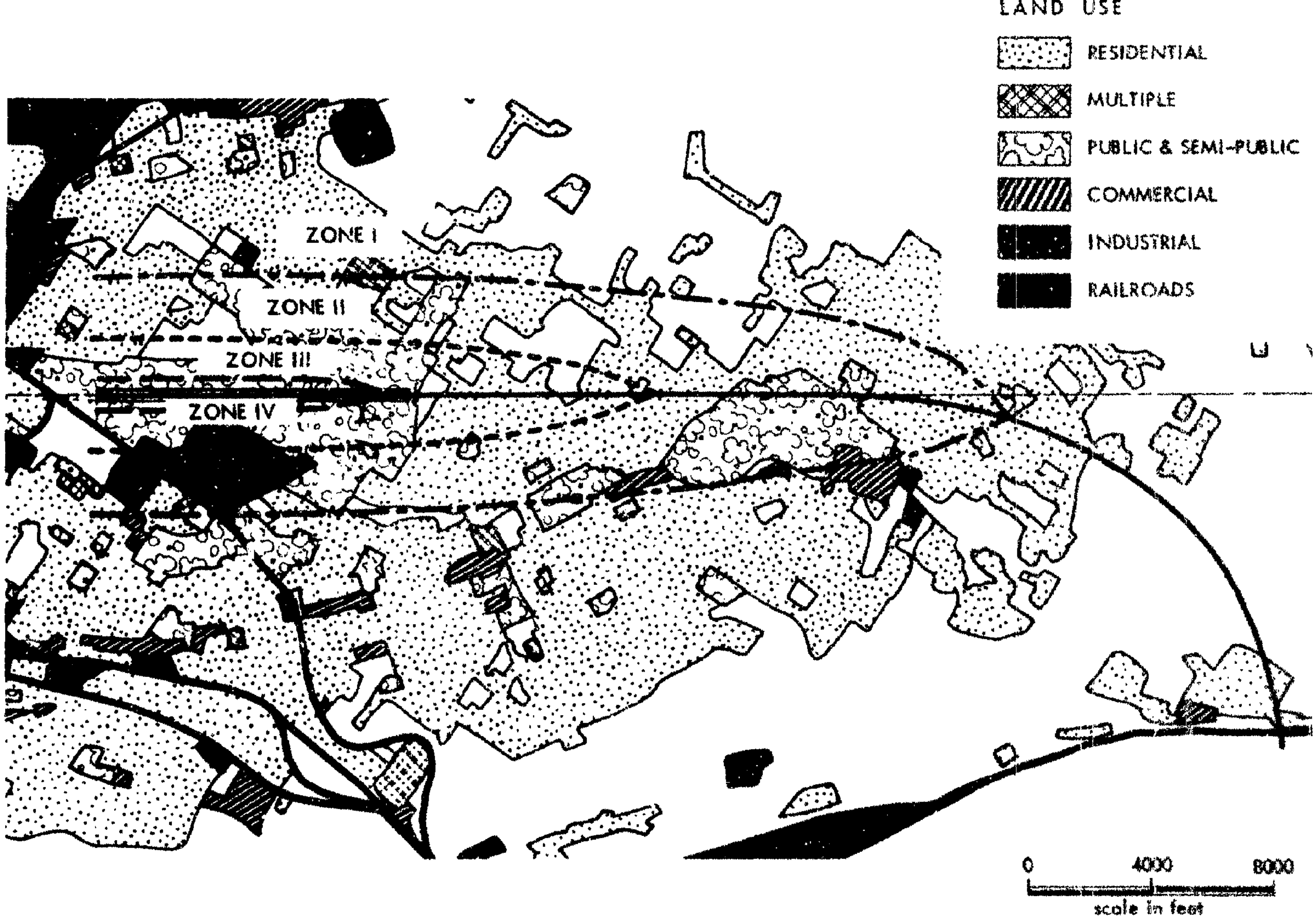


FIGURE 1. AIRCRAFT NOISE SENSITIVITY ZONES DISPLAYED ON LAND USE MAP OF BIRMINGHAM, ALABAMA
(Medium Range Turbofan Transport Takeoffs from Runway 5, Birmingham Municipal Airport)

IV. RESULTS OF STUDY

Land use compatibility studies were conducted for aircraft operations in four cities: Los Angeles, San Francisco, Birmingham, Alabama, and Miami, Florida. Table II shows the results of the analysis for the different airports. The aircraft operations considered and the corresponding runways are noted on the table. Also listed is the total land area within Noise Sensitivity Zones II, III, and IV, and the percent of this land area lying within each of the three zones. The percent of land usage considered marginal or unsatisfactory is also listed in the table. Not all flight operations or flight paths were studied for the various airports. Situations were selected at each of the airports for various comparison purposes.

The areas and percentages given in Table I were determined with respect to some arbitrary land boundaries that might well be modified in a more detailed study. For takeoffs, we considered land areas beginning at distances 10,000 ft from the start of takeoff roll. Thus land areas lying to either side of the runways (or beyond the end of the runway where the runway was less than 10,000 ft long) were omitted. For landings we considered land areas only up to the landing threshold. We also limited our consideration of noise exposure from takeoffs and landings to land areas lying within 58,000 ft from start of takeoff roll, or in the case of landings, 58,000 ft before touchdown.

Although from such a limited study one would not expect to detect any consistent trends, it is of interest to discuss each case, pointing out some similarities and dissimilarities that are pertinent in studying land use problems near and around airports. In several of the cases, one can also detect patterns in land use that will serve to illustrate and confirm the existence of "known" noise problems existing at the given airfields.

A. Los Angeles International Airport

Landing operations at two runways, Runway 25L and Runway 24, were considered. Runway 25L currently handles most

TABLE II

SUMMARY OF LAND USE CLASSIFICATIONS UNDER AIRCRAFT FLIGHT PATHS

AIRPORT	AIRCRAFT OPERATION	RUNWAY FLIGHT PATH	NOISE SENSITIVITY ZONE	TOTAL		% LAND USE			% LAND USE	
				AREA (acres)	POPULATION	RESID.	COMMER. and INDUST.	UNDEV. PARK RECR.	DOUBTFUL	UNSAT.
Birmingham Municipal, Alabama	Takeoff[1]	R/W 5, turn to N	II	2,010	8,100	58	2	40	0	0
			III	380	2,400	75	1	24	75	0
	Takeoff[1]	R/W 5, turn to E	II	2,010	8,200	57	3	40	0	0
			III	380	2,400	75	1	24	75	0
	Landing[1]	R/W 5, from N	II	1,860	22,100	72	13	15	0	0
			III	525	4,300	65	18	17	65	0
			IV	45	(400)	59	8	33	33	59
	Landing[1]	R/W 5. from S	II	1,910	23,500	70	15	15	0	0
			III	525	4,300	65	18	17	65	0
			IV	45	(400)	59	8	33	33	59
Los Angeles International, California	Landing[2]	R/W 25L	II	2,900	65,100	74	--	--	0	0
			III	2,900	52,500	68	21	11	68	0
			IV	510	7,700	65	19	17	18	65
	Landing[2]	R/W 24	II	2,900	57,700	59	--	--	0	0
			III	2,900	45,600	55	29	16	55	0
			IV	510	5,840	64	32	4	32	64
Miami International, Florida	Takeoff[3]	9L, straight	II	6,380	--	60	28	12	0	0
			III	3,690	--	46	50	4	46	0
			IV	455	--	15	62	23	62	15
	Takeoff[4]	9L, straight	II	4,510	--	50	42	8	0	0
			III	1,025	--	16	67	17	16	0
			IV	11	--	5	90	5	90	5
San Francisco International, California	Takeoff[3]	28R	II	11,300	86,800	39	8	53	0	0
			III	3,450	25,300	41	25	34	41	0
			IV	85	(200)	48	43	9	43	48

[1] Medium Range Turbofan Transport Aircraft

[2] Turbofan and Turbojet Transport Aircraft

[3] Large, Long Range Turbofan Transport Aircraft

[4] Large, Medium Range Turbofan Transport Aircraft

landing operations. However, with a proposed extension of Runway 24, there is possibility of handling a large number of landings on Runway 24. Thus we chose to compare the land use under landing paths for each runway, assuming the same number of operations on each runway.

Comparison of the land use data tabulated in Table II shows that percentages of residential land lying in Noise Sensitivity Zones III and IV vary over a relatively small range of 55% to 68% for either runway. Slightly less residential land is exposed to noise from landings on Runway 24, than to noise from landings on Runway 25L. The total number of people living in Noise Sensitivity Zones III and IV is approximately 15% less for Runway 24 than Runway 25L.

Also to be noted for both landing situations are the relatively small percentages of undeveloped land, or other land uses that might be termed noncritical with respect to noise. On the basis of land use similarities and the large number of people in residential areas under either landing path, one would therefore expect that the noise problems now encountered for current landing operations on Runway 25L would also be encountered to the same extent by a shift of landing operations to Runway 24.

B. <u>San Francisco International Airport</u>

This study covered takeoff operations from Runway 28, a runway that handles approximately 40% of jet takeoffs. The Noise Sensitivity Zones are based upon operations of long range turbofan jet aircraft. Note the large increase in land areas falling in the different Noise Sensitivity Zones compared to the Los Angeles figures. This reflects, of course, the generally larger areas of land exposed to the same type of noise environment for takeoff operations compared to landing operations.

One will also note that, in comparison with the Los Angeles landing operations, there is a smaller percentage of land devoted to residential use and a much greater proportion of land that is undeveloped or devoted to noncritical land uses.

C. Birmingham Municipal Airport, Alabama

Takeoffs and landings on Runway 5 by medium-range turbofan aircraft were studied. For takeoffs we considered an initial straight-out path, with either a turn to the left or a turn to the right. For landings we considered aircraft approaching either from the north or from the south, then turning to make an approach on Runway 5.

In comparison to the previous cases, the amount of land in the different Noise Sensitivity Zones is considerably less. In fact, no land falls into Noise Sensitivity Zone IV; this results from our arbitrary boundary conditions, as discussed earlier. The smaller land area reflects the lower volume of traffic operations and, in the case of takeoffs, the steeper climb profile typical of medium-range transport aircraft.

D. Miami International Airport, Florida

Takeoffs from Runway 9L for two types of aircraft were compared:

a) long-range turbofan aircraft

b) medium-range turbofan aircraft

Thus the differences in Noise Sensitivity Zone areas primarily reflect differences in takeoff altitude profiles rather than differences in noise characteristics or volume of flight operations. Note that with the medium-range jet operations there is a much lower percentage (and in absolute area, an even smaller amount) of residential land exposed in Noise Sensitivity Zones III and IV as compared to the long range turbofan operations.

V. SUMMARY

This study demonstrated the application of aircraft noise information and methods for rating land use compatibility with aircraft noise to determine the extent of "marginal" or "unsatisfactory" land uses existing in land under and adjacent to aircraft takeoff or landing paths. Actual land use and flight information for varied flight operations at four different airports were utilized to illustrate the technical approach.

Noise contours were calculated either by hand or by computer. Land areas were computed by planimeter because the computer computations, originally planned, were found to offer no advantages for the limited handling of land-use data encompassed in this study.

REFERENCES

1. D. E. Bishop, "Development of Aircraft Noise Compatibility Criteria for Varied Land Uses," Part II of SRDS Report No. RD-64-148 (December 1964).

2. Bolt Beranek and Newman Inc., Technical Report, "Land Use Planning Relating to Aircraft Noise," FAA (October 1964). Also published by Dept. of Defense as AFM 86-5, TM 5-365, NAVDOCKS P-98, "Land Use Planning With Respect to Aircraft Noise."

3. W. E. Clark, "An Approach to Analysis of Aircraft Noise Problems Using Computer-Aided Techniques," Part I of FAA SRDS Report No. RD-64-148 (December 1964).

4. "The Comprehensive Plan, Birmingham, Alabama," Birmingham Planning Commission and Harland Bartholomew and Associates (1961).